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THE KNOWN AND THE UNKNOWN *

BY
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The dream of the man of science is to understand nature. Alas, this word "understand" is like a chameleon who changes his color with the setting in which he finds himself. To the layman, understanding usually means, or involves, an explanation in terms of notions and principles which he has come to accept. However, he probably accepted these principles at an age when he was too young to question them, and when he had grown to maturity at which he might question them, they had become so familiar that it seemed unnecessary to question them further. And so, he is philosophically happy in these principles. It requires very little effort to prick his philosophical conscience in this matter and show him that his acceptance of these notions and principles is indeed open to criticism. However, you may rob him of his philosophy, but you cannot rob him of his happiness. Once he is happy, he stays that way in spite of all efforts on your part to show him that he ought to be morose. He will simply tell you that you are talking metaphysics. As a last resort, he will appeal to his own personal anatomy in telling you that deep down in his very bones he feels that such and such is true, and beyond his bones you will not get.

The whole of what today we call science is the product of the last five per cent of the period of man's civilization, and 90 per cent of the picture which science has evolved has come into focus in less than one per cent of that period. If we start 300 years ago, when science, as we know it, began, we find the brilliant discoveries of Newton and Galileo giving the first great jolt to the beliefs which 6000 years of growth had

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implanted in the brain of man. Then followed a period of assimilation of the new philosophy and its development to the point in which the mind was at least partly content in the belief that *something* was understood. The second great period came with the discovery and development of electrical science in the last century. The ideas born of the age of Newton were strained to their limits to accommodate the new phenomena in the realm of what then figured as common sense and without invocation of the concept of the miraculous. Then came the discoveries of the present century, culminating in the age of atomic science now with us. In all of this development, common sense wandered in company with the philosopher as a frightened companion knowing not what might be expected of him from day to day. The nonsense of the past was continually becoming the common sense of the present, and the nonsense of the present was ever fated to become the common sense of the future. This attempt of common sense to accompany the development of discovery, even though with continual protest, was all that stood in the way of accepting the new things as miracles. I once knew a man who knew very little of what he was supposed to know, and when confronted with some statement outside the realm of his understanding he was accustomed to save face by uttering the remark: "Of course, that goes without saying." And so common sense tried continually to brush off the wonder of it all by an equivalent evasion. One has only to imagine himself going to sleep for 25 years, so that the adaptation of common sense is suppressed for that period, in order to see the realities in their true light. If our imaginary Rip van Winkle went to sleep towards the end of the last century, we can imagine his dividing discoveries into those of his past and those of his future. The past has been nurtured to his appreciation by the common sense of his era. If, in his future, he should envisage a situation in which a man speaking in Germany would be heard in New York without visible means of communication, he would undoubtedly class such an occurrence as outside of the realm of science. I will guarantee that if he slept for a quarter of a century and then awakened to confront such a phenomenon, every fiiber of his nervous system of common sense would cry out that he had indeed witnessed a miracle, and if you tried to bridge the twenty-five years with explanations of wireless theory and the like without allowing the slow transformation of common sense to take place in his being, he would, quite rightly, maintain that you were simply trying to explain a miracle by basing the miracle upon a lot of other miracles which were just as much out of the range of understanding as was the primary miracle itself.

Theories of scientific phenomena are not *explanations*. They are simply processes of correlating and cataloging the facts. We start with a series of observations of nature and we describe what we see, hear, or feel in terms of words. This provides no explanation, although it must

be confessed that many people succumb to the belief that they understand something when they have given it a name. A name covers a wide territory of ignorance, and many attempt to beguile themselves into partial understanding when strange things happen by attributing them to instinct, or magnetism, or what not. If the word chosen has an impressive sound and is used by learned men in other connections it is supposed, of its charity, to be able to shroud all ignorance with the illusion of understanding.

I take it as an established fact that there is evidence of design in the universe. This is a matter with which I dealt in an address before the Institute two years ago.[2] However, the nature of that design is not necessarily evident in its entirety from our limited accumulated experiences.

The serious philosopher who has learned to know of the pitfalls of so-called common sense in his understanding of things, seeks to set up what we may call a one-to-one correspondence between the experiences of nature and some form of representation which is his own invention and which he can manipulate with dexterity. One might imagine an astronomer trying to correlate the facts of the *Nautical Almanac* by giving the heavenly bodies names comprised of letters arranged in such orders that by manipulating the letters according to some prescribed rule he could set up correlations with what he observed. If his scheme were successful in correlating the events of the past over the fairly wide range of his experiences, he might indulge in a faith that perhaps it would also predict the future. And such a hope would be at least worth a test in promoting a search for the things predicted.

I present this idea to you in all its nakedness so that you may be truly horrified and give up all hope of finding a place for common sense in it, because such a procedure really corresponds in essence to what the mathematical physicist is doing. The great strength of the procedure founded upon what we may call the mathematical model, lies in the great richness of potentialities for expressing formal relationships inherent in mathematical processes, a richness so great that we may hope to set up a useful correspondence with almost any set of phenomena and *some* branch of mathematical science. If you ask what the use of such a procedure is, the answer is simply that, with the formal scheme of mathematical relationships before us, we may find ways of simplifying these relationships by expressing them as the natural outcome of a fewer number of starting points or principles than at first sight seemed required. Thus, all Euclid's Theorems come from but five postulates. As I have pointed out so many times in lectures before this Institute, the great power of Newton's formulation of the law of gravitation lay in the fact that, instead of viewing all the facts of astronomy as a conglomeration of separately occurring phenomena, we were able to view

[2] "Is the Universe Planned?," this JOURNAL, Vol. 255, p. 367 (1953).

them as the outcome of a single law. The process is one where, by saying one thing, we can deduce many consequences as a result of that one thing. We can deduce the motions of all of the heavenly bodies and many other things about them. This does not mean that we understand the one thing from which these consequences were derived. The process has been one of bringing order into our thoughts rather than understanding in the naive sense.

Of course, it is true that when order has been created in this manner and has worked successfully for a long time, common sense will descend upon the structure and claim a place in it. The mind will gradually grow to recognize as intuitively obvious some of the fundamentals which control the operations of the mathematical scheme. In order to illustrate how that which is customary in experience can grow to appear a necessity of fundamental logic, I need only remind those of you who think it is obvious that the angles at the base of an isosceles triangle are equal must face the recollection of the great task some of you found in your endeavors to prove this apparently obvious statement when you encountered it in Euclid's proposition No. 5 of Book 1, where by tradition it has become labelled "the asses' bridge" because the diagram representing it looks like a bridge and it was a bridge which the asses of the class never succeeded in crossing.

Now even the mathematical physicist has had to content himself by setting up mathematical schemes which comprehend but a portion of the whole realm of nature, the portion which he happens to be interested in at the time, and a portion of the complete scheme will naturally show features characteristic of that portion and not represented in every other portion. One might say that the grand ambition would be to set up a scheme of philosophy which comprehended all of the happenings of nature in their entirety, a scheme which would bring all nature into one frame, so that the same scientific language applied throughout. Alas, if this were done, the description would be so complicated and so divorced, in what we may call its pictorial representation, from any one of the separate domains which interested mankind at the moment that it would be of very little use as a stimulant to thought. Even in the separate fields themselves the sharpness of the intuitive picture tends to become blurred by generalities and while, in the blurred form, it is more unassailable, it is also less intuitively suggestive. The smaller the domain of interest, the sharper are the pictures which the domain invites, but the less representative are the pictures of something characteristic of the complete domain of *all* interests and the more bizarre are those pictures when transferred to some other domain to which they do not naturally belong.

There are certain features which are characteristic of all the land which comprises our earth. It is not inconsistent with the complete logic of the situation that palm trees should grow in Florida and not in

Iceland. However, if, living in Florida, I have limited my vision of the earth as a whole so that I have come to regard palm trees as a necessary evidence of the existence of life, I shall tend to become worried by what would appear to be an inconsistency of things in not finding these products of nature in Iceland.

Thus, every high school student acquires a feeling that he knows what is meant by mass. It, so his books tell him, is the amount of matter in a body, whatever that may mean. The crude statement is vague and meaningless to the philosopher, but it is purposeful for ninety per cent of the use that the high school student will have to make of it. On the other hand, when that student comes to the stage of studying the theory of relativity or electrodynamics, he has to realize that this mass is something which changes with velocity. The firmer his conviction that he understood matters when he thought of mass as the amount of matter in a body, the harder his mental task in generalizing his concept. As he goes further in his studies, he has to adopt a language in which mass and what is called energy, and which was formerly a separate thing, become merged into one greater and more general concept, a concept capable of much wider application, but one which, in any particular form of use, has to be crystalized into the more special characteristic adaptable to that use.

In a sense we have, in a monarchy, an analogy with this kind of thing. If one tries to define exactly what the monarch is and in such a manner as to fit all of his supposed activities, the ultimate picture of the individual may not be very revealing. And so when the monarch appears in a naval ceremony he is dressed as an admiral of the fleet. When he appears in a military ceremony he is dressed as a general of the army. When he addresses an academic society he wears the robes of his honorary degree. Apart from the mere tradition involved in such a procedure, the raiment which at any time he wears does serve, in a way, to concentrate attention upon those elements of his total functions which are concerned with the interests of the assembly in which at the moment he finds himself. But there is philosophic danger in concentrating too much upon the special features appropriate to the occasion, for some of the specialities of the immediate activities may loom in such importance as to claim a place on all occasions. The sword of the admiral may assume such significance in the activities of the admiral that I find myself unable to comprehend the meaning of its absence when I view the monarch, not as an admiral, but as a Doctor of Laws. In any epoch, all knowledge of the known has its specialized features, its admirals, its generals, its scholars, and these, having claimed, in their own domains, prerogatives in their own right, may seek to enforce some of the prerogatives in other realms of activity. Born in the realm of the known they may claim authority in the unknown and deny all meaning to situations which fail to make use of their special attributes.

And so, as maturity in philosophy progresses, we begin to see the dangers in the primitive idea of basic understanding, in that intuitive conviction known as "horse sense," and definable as the kind of sense possessed by horses. While admitting design in the universe, we begin to realize that our business is the humble one of seeking to learn of that design from the design itself, rather than in our own way, a way in which we bring to the task of understanding our own little building blocks of thought which we have acquired here and there, and demand that the workings of nature shall conform to what we can make from these blocks. Even though we may claim that the blocks may fit all of the present "known" in nature, they may well be symbols of the specialities pertinent to the present "known," the sword of the admiral and the robes of the savant. Even though these bricks may fit all the science of today, we must remember that science—our science—is the servant of nature and not its master. There is no master science which controls the universe other than that science which fits all the doings of the universe. Common sense is the child of nature, not its sire.

And so I think we may say that generalization in man's mental activities is a process by whose development he more thoroughly understands, even though he may be more humble in the significance of that understanding. But specialization, with its more concrete picture of the matter at the moment in hand is a process by which, usually, man must act.

If I should ever visualize a complete harmonization of all the activities of nature, I should still expect to find a kind of United Nations of philosophy, but an organization divided in many of its practical affairs into separate groups in which different languages were spoken and different matters dealt with. The special feature which I should expect to find in this assembly and which would not be threatened even if all the nations of thought were completely separated would be a means by which the doings of one group were not incomprehensible to those of another, but one in which the doings of all groups were really in harmony although a superficial view of the situation, which did not take account of the special problems which confronted the different sections, would appear to make them at variance one with the other.

The kind of situation which we here have is closely related to a set of circumstances embraced under that much abused word, the last refuge of all fools and, alas! of many wise men, the word "consistency." Personally, I have always refused to be bound by the dictates of consistency, or perhaps I had better say of *superficial* consistency. Of course, when one analyzes this matter sufficiently far, no two situations are ever alike. They may appear to be very much alike and it may appear that if one does one thing in one case and a different thing in the other case he is inconsistent. On the other hand, if one takes into account the different circumstances involved, it may frequently happen that, in the last anal-

ysis, these circumstances are very significant and powerful to convert the apparent inconsistency of action in the two cases into an over-all consistency of a much more profound nature.

Now you may wonder why I am laying such stress on these apparently rather abstruse matters. I will tell you. The different domains of knowledge contain their various specializations, and they place boundaries around themselves, boundaries which should really have doorways connecting one domain with another. Insofar, however, as one is concerned with the activities in any one of these domains, the doorways are, to some extent, a nuisance. They permit drafts from one room to another in the form of ideas which tend to conflict with the orderliness of things in any one of the rooms in question. In one of these rooms the workers have arranged their papers quite neatly in order on their appropriate desks, and a puff of wind from an adjacent room will occasionally upset that order a little and cause annoyance. For this reason, it is perhaps expedient to close the doors, so that there shall be no drafts. And yet when the doors are closed and one looks through the windows separating the different rooms one is apt to come to the conclusion, on looking from room A into room B, that that which is going on in B is completely nonsensical, illogical, and in the last analysis, perhaps impossible. And so one pulls down the blinds so that he cannot see into these rooms and maintains that those things which appear to be happening do not happen at all. One becomes like unto the old farmer who, visiting the zoo for the first time, saw the giraffe, and on looking up and up and up until he finally saw the head of that animal so far above him, closed his eyes and muttered: "There ain't no such animal."

Even in the limited domain of what we call science, these matters have become evident in the growth of that science from medieval times unto the present day. The philosophies of ancient time decreed that there could be but seven planets because there were but seven days in the week and because seven occurred in significant manner in many other connections concerned with man's activities. And so, when Galileo discovered additional heavenly bodies, the conventional thought of the day dismissed them as apparitions, or as curious optical distortions inherent in the telescope, or things invented by the devil. Yet, with the new objects continually before one's eyes, it was indeed difficult to deny that they existed. And when man had advanced to the stage in which he did regard these bodies as real things rather than pinholes in a great dark sphere which shrouded the earth from the vision of heaven, when he came to regard each planet as a real thing, then common sense remoulded itself and accepted the facts as harmonious with its new structure. In the spirit of this concession, it came to regard the philosophy of Newton as acceptable. Truly, in envisaging the heavenly bodies as apparently acting on each other when separated so widely in space, intuition was a little shocked and cried out "How can matter act where it is not?" However, the situation was no longer re-

garded in the light of a miracle, but as something which remained to be understood.

Then, two hundred years later, and heralded by a few apparently unimportant phenomena concerned with the power of certain bodies to attract light objects when suitably rubbed, came the dawn of the electric era. The hope was to understand the new phenomena as extensions of the ideas involved in accepting the laws of dynamics and the theories of astronomy. The debt to the past was paid by recognizing its need of an all-pervading medium, an aether, by which light bridged the great spans of space, and by which perhaps gravitation could be understood. And then this aether, craved so strongly by the past, became the medium in whose properties the facts of the infant science of electricity were to be understood. The great mathematicians of a hundred years ago wrestled hard to preserve the intuitive spirit of the past, but were forced continually but inevitably to a recognition of the fact that the ideas of the past could not contain the new present, and the impossibilities of the past must be admitted as the possibilities of that present. The aether must have strange properties, like unto those of no known substance. Among other things, it must have, in some circumstances, density and rigidity greater than steel, while in others it must be more fluid than water, more fluid than the air we breathe. Had not the mathematicians worked so long with this supposed medium in an endeavor to find some way in which it might be conceived as working normally, had they been confronted at the beginning with the characteristics which their researches demanded of this medium at the end, and had they not passed the stage of sophistication of ordinary mortals, they would undoubtedly have been forced to conclude that the aether was indeed a miraculous substance. To avoid being pestered by others and by as much of their own material consciences as had survived from their own youth, they sought to avoid the question and shroud in mathematical symbolism the relation between the facts and the models and pictures in terms of which an explanation might have been hoped for. Among them, however, were many diehards who regretted the passage of the good old days. The matter is illustrated by a comment in Sir Arthur Schuster's "Theory of Optics," written as late as 1904, and it must be remembered that Schuster was one of the world's high priests of natural philosophy in that epoch. He writes: "The study of physics must be based on a knowledge of mechanics, and the problem of light will only be solved when we have discovered the mechanical properties of the ether." Writing in another place of Maxwell's equations, he remarks: "The fact that this evasive school of philosophy has received some countenance from the writings of Heinrich Hertz renders it all the more necessary that it should be treated seriously and resisted strenuously." In reading this quotation, one must observe that Schuster was actually a contemporary of many of us who are today alive. In

fact, so near is he to my own epoch that I have been told that he was one of the men largely responsible for my coming to the Carnegie Institution of Washington from England as a young man.

And so, apart from the diehards who yet clung to materialistic explanations, towards the end of the last century, there seemed to be a period of contentment in which the new philosophy so deplored by Schuster was regarded as acceptable. You will observe that steps towards minimizing intuitive *explanations* and accepting as satisfactory a harmonious description of the phenomena were already being taken. However, there were many shades of opinion ranging from the staunch conservatism of Schuster to the complete radicalism as regards electrodynamics ushered in by the era of relativity. Between the two extremes were those who hoped for some kind of compromise between the new and the old.

The acceptance of the new philosophy ushered in by Maxwell and Lorentz was accelerated by the many successes which the formalistic mathematical equations had in predicting, guiding, and bringing to fruition the multitudinous devices of electrical engineering, including wireless telegraphy and telephony. The discovery of the electron provided another field of activity, a field of activity which later developed into the whole domain of the electronics of today. The part played by the electron, a fundamental constituent of the very atoms themselves, encouraged the view that even the behavior of these atoms was on the point of being understood, at least in terms of the relatively new philosophy of the electromagnetic theory. However, there were dark clouds upon the horizon of speculation. The insistent probing for an understanding of the role played by the supposed all-pervading aether leading to the theory of relativity served not only to make understanding in the old sense hopeless, but struck at the meaningfulness of such understanding of things as before had seemed secure. Our very concepts of space and time were called before the bar for critical judgment and went out condemned as tarred with the mysticism of naive intuition. Such meaning as there had been in the old Newtonian philosophy was torn to shreds, and while the mathematical mechanisms of the old theory remained as tools of calculation, such partial *reasons* for the behavior of things as had been an encouragement to what we may call the old materialistic philosophy were found to be without that fundamentality of origin which many had hoped to find in them, and they provided litttle more than the function of mental drugs useful only to those who had become addicted to such drugs.

And from another angle, the attempt to tie up atomic behavior with the old pictures of mechanical mechanisms led to continual inconsistencies in interpretation. Starting with bold attempts at understanding, born soon after the discovery of the electron, an attempt to preserve some kind of a picture in the old sense led to the Bohr Theory, a strange

wedding of the old with what was demanded of the new, a wedding sanctified only by an agreement to allow the old to be present at the wedding festivities and subsequent life of the family, with no rights of participation in any of the doings of the family.[3] There were two things, the picture and the actions. The picture gave a little comfort of something to look at, but the actions were hidden behind the picture and so obscured that there was grave doubt as to whether they had any connection with the picture. Finally, in the modern quantum theory, the picture was taken down from the wall entirely, and in its place were hung a series of rules for calculating what would happen in this case and that.

I will venture to say that if the philosophy of the modern quantum theory were presented to a philosopher of the mid-Victorian or even the late Victorian era, he would be compelled to regard it as a formulation of mysticism more strange, more out of keeping with what he thought had been the experience of his life, than any occult manifestations which could be presented to him by the most ardent student of such phenomena. Only the gradualness of the development has saved it from such a characterization. Perhaps it is not even safe to say this, for indeed, the development has been by no means gradual. Perhaps it would be better to say that only the heat of the chase after the ultimate truths in nature and discontent with the false comforts of the supposed realities of the past have encouraged the investigator to discard all cries of protest from the past as regards the road he was pursuing, and have provided him with the urge to speed only towards the truths, regardless of his means of locomotion or the scenery of his travels to that goal.

I have, of course, no quarrel with the quantum theory in this matter. Indeed, I think before it has fulfilled its purpose it will travel still further in the journeys of the abstract, but even taking it at its present stage, I deem it fair to assume that whatever mystical phenomena one cared to propose, phenomena concerned with this world or the next, the task of correlating such phenomena into a train of logical relationships with one another and with the activities of nature as we know them is unlikely to invoke a scheme of correlation, or a theory if you prefer the old word, which is more bizarre to the thinking of even half a century ago than would be the scheme embodied in the quantum theory.

In what I have said so far, I have tried to emphasize that even in a scheme of philosophy which successfully embraced all nature, the known and the unknown, the study of the individual parts of the scheme would show features which appeared quite diverse, and indeed, inconsistent with one another, even as the existence of palm trees in Florida may seem inconsistent with their absence in Iceland.

[3] The physicist will here observe that I am calling attention to the fact that the Bohr orbits played no role in the emission of radiation, and even the electron itself, while given the credit for emission of the radiation, carried no mathematical credentials to certify how it carried out this mysterious function.

Now the great domains of the known tend to divide themselves into categories where the superficial alikeness of pairs of the domains varies vastly with the particular domain chosen for comparison. That combination of studies which we call Physics presents reasonable consistency, even in the naive sense, in its own domain. In fact, it was this feature which caused such studies to become segregated into a single discipline. The same may be said of Chemistry, and of Biology. As time progressed the demands of physics within itself called for a generalization, and a similar thing happened in chemistry. These generalizations began to overlap and have continued to overlap more and more as time has progressed, so that there are few matters in chemistry and physics in which the same language may not be spoken. This fusion has also occurred to some extent between chemistry and physics and the biological sciences, but here the harmony is by no means so complete. It is indeed true that we have reached the stage at which, through the large molecules encountered in the viruses, we begin to sense a glimmer of the transition from inanimate to animate matter. However, the beginning is primitive indeed, and one who seeks to view from its vantage an understanding of all the facts and potentialities involved in the crowning achievement of nature, the evolution of man as we know him, is like a prehistoric man who, viewing the heavens, has before him all the developments of physical science to discover before he can hope to be content in an understanding of all he sees. Prehistoric man, who had no thought of or experience of such developments, took refuge in mysticism, and such things as baffled his understanding were attributed to divine agencies which, indeed, found their bodily realization in the heavenly bodies themselves.

As I have remarked, the physicist of the century's beginning was very conservative, very economical in permitting the entry of new philosophical concepts into his science. However, he was also very conservative in admitting new concepts which were not so philosophical. With the electron and the proton accepted as fundamental elements, fundamental bricks, in nature's structure, the endeavor was to correlate all phenomena in terms of the activities of these two entities. It was not that the possible existence of a neutral particle never occurred to the physicists. Such a possibility would occur to anyone. However, the physicist had created a kind of mathematical structure which he did not wish to spoil. A neutral particle figured as a kind of interloper for whom there was no place in the edifice which had been built, and so it was only when the cold facts of experiment insisted upon the acceptance of the neutron that the architects of the mathematical palace which had been built for the electron and proton were willing reluctantly to modify that structure so as to admit the neutron, in spite of the fact that the neutron soon became accepted as one of the three fundamental building blocks of all the atoms which comprise matter.

The situation presented by the neutron was rather curious. Here, as we know today, was a particle which played a fundamental role in the operation of everything, but a role which was hidden from direct observation. The experiments which it was necessary for a physicist to do in order to make the neutron "visible" in the scientific sense, as distinct from something whose presence had to be inferred from concealed activities, the kind of experiments necessary to do this were the kind of experiments which very few physicists would think of doing and for which there was very little suitable equipment available for those who had thought of doing them. Similar remarks might, indeed, be made in connection with the discovery of the proton and the electron. Before they became known, the chance that anyone would do the kind of thing which would reveal them, other than through remote consequences of their activities, was infinitesimal. Directly their existence became established, everybody was doing such experiments continually.

I think it necessary to appreciate to the full this situation as represented by the attitude of the science of the past in order to attune oneself to the needs of the future. The past illustrates two types of resistance natural to the investigator. The first lies in his reluctance to accept new concepts if those concepts do not force themselves upon him through experiments for which he has to make no special provision, and indeed force themselves upon him in plenteous supply. The second is reluctance to modify the theoretical structure so as to accommodate the new interlopers if their accommodation is not already provided for. This reluctance is not necessarily born of the *difficulty* involved in suitably modifying the structure, but of the lack of desire to make the modification. Let me take a very drastic example of the latter situation.

Suppose I should wish to harmonize the possibilities involved in the coexistence of two universes, A and B, both in the same space, each comprising its own structure, with living entities of the degree of development of man, if you like, as part of them. And suppose further that I wish to provide for a situation in which the beings of universe A are quite unaware of the existence of the beings of universe B. You may assert that the whole notion is fantastic. About that I will not argue with you. I will only assert that the fundamental mathematical principle involved in providing for a situation of this kind is something which mathematicians are using every day without blushing. For a moment, I should like to address myself to the technically trained physicists. The other members of the audience can entertain themselves by looking at their technically trained friends and be ready to apply first aid if any signs of apoplexy or other erratic symptoms appear to develop.

I ask you to think of our very old friends, the circuital differential equations of the Maxwell-Lorentz theory. I exclude the force equation, which is not part of them and is not derivable from them.

Our equations are linear, so that we can add any two solutions and

the result is a solution. Now we can find a solution for the field corresponding to an electron (positive or negative) moving in any manner we like to assign. If we do this for each of our individual electrons and add the solutions, the result will be a solution, and in this solution we have a situation in which not only do the positive electrons move independently of the negative, but every electron moves independently of all the others. In the sense that complete independence of activity is symbolic of unawareness, we may say that each electron is unaware of the presence of all the others, so that indeed we have, not merely two independent universes in the same space, but as many universes as there are electrons. Each electron is alone in its own universe.

Interaction between these electrons is provided only by the force equation, which is something not contained in the circuital relations themselves. Now it does not take much ingenuity to modify the nature of this force equation in such a way as to provide very rare occasions in which the motion of one electron becomes sensitive to the presence of another. If events of this kind are sufficiently rare, their occurrence might well be deemed as miraculous by the electrons themselves if, for a moment, we endow them with sufficient consciousness to permit them to be aware of strange things happening to them. Indeed, the whole form which the quantum theory has taken in recent years is one still more adapted to the kind of behavior envisaged in this elementary problem.

We imagine systems—atoms, for example—as capable of assuming certain states. In these states they possess the potentiality of existing for ever without change and, to extend the analogy slightly, completely unaware of one another's presence. Only under exceptional conditions, through the agency of what are called perturbations, does anything happen to an atom, and when something does happen, that something amounts to a change from one state to another. However, it is of the essence of the quantum theory that, of the various kinds of change which may occur, there is no certainty of the occurrence of any particular change in preference to any of the other possibilities which may be open. All is a matter of chance, the chances being weighted as regards the different possibilities. If ever the mathematical physicist set out to make matters more definite in the story, without destroying the structure which he has already created, it would be by superposing upon that structure something of the nature of free will of decision on the part of the atom, a free will, however, of such a kind that that free will was controlled to the extent that, as regards the *average* happenings for all atoms, there was no free will.

Linearity of the fundamental equations, the symbol of non-recognition of one entity or group of entities by another group, is a creation of the mathematician for the simplification of his calculations. It is a creation which, I often think, tends to kill the goose which lays the

golden eggs in the matter of descriptions of the vital features of phenomena which, after all, are the influences of one set of things on another. And so the mathematician has to superpose upon sterile linearity something else which provides for the interesting working of things. The peculiarity of this process and of its implications becomes submerged in the non-personal nature of the entities, electrons, protons, neutrons, etc., with which he deals; but if the process were applied to the doings of human beings, the results, in terms of our ordinary characterization of things, would, in many cases, merge upon the occult or the miraculous.

Take, for example, a situation in which the quantum theory predicts the emission of a neutrino. This peculiar entity is something which, in spite of all his efforts, the physicist has so far been unable to observe. In terms of his mathematical formalism, he has no power of accounting for this entity ever doing anything which would constitute an interaction with the world of entities from which it was born. If ever there were, in the affairs of man, a spirit, a soul, which stood apart from man's ordinary activities as a disembodied entity, the neutrino has certainly a right to pose as a quantum theory analogue of it.

One of the main things which I wish to emphasize in the discussion at this stage is the fact that there is very little force in an argument which denies the existence of phenomena because they do not cry aloud as to their presence from the theories we have built to correlate other phenomena. The theories are very elastic structures. Not only is the change in them necessary to accommodate new phenomena frequently very small, but we can at times see how the same kinds of development of the theories which have taken place to correlate the facts in the realm of physics alone could well be incorporated to correlate phenomena remote from the realms which we customarily associate with physics.

Another point concerns the fact that even in the theories of physics itself we have been accustomed to prepare the ground for correlating phenomena of all degrees of rarity of occurrence, even to the extent of correlating in the scheme of philosophy the concept of the neutrino, whose chance of ever making itself evident in the positive sense seems, as far as results have so far indicated, to be zero.[4]

But we need not go to such lengths to find, even in the everyday activities of physics, phenomena of such rarity that, from the standpoint of the individual entities concerned, their occurrences would be regarded as miracles. And, indeed, these occurrences, miraculous to the individuals, constitute most of the things which, in nature as a whole, are the things which characterize the most observable, outstanding, and useful features of our universe.

At this point, let me invite back from the realms of Morpheus the

[4] Certain recent experiments of an *indirect* nature have given some evidence of the existence of neutrinos.

non-technical members of the audience while I give a few illustrations which I have cited on other occasions before the Institute.

In every cubic inch of the air which you breathe there are about ten thousand molecules which are in a peculiar state. They have lost an electron, and are consequently charged to the extent of one proton. To us there is no miracle about this matter. I could bring into this room a comparatively small piece of apparatus with which, in five minutes, I could measure the number of these peculiar molecules. Yet, think what a strange phenomenon we have here when viewed from the standpoint of the molecules themselves. For, that cubic inch of air contains about five hundred million million million molecules, and only ten thousand of them have lost an electron. In other words, out of every fifty thousand million million molecules only one has lost an electron. If a molecule were to go about saying that it had once seen one of its brothers which had lost an electron, the story would be less likely to be believed than would the assertion by some person that he had seen a man with two heads, if he were the only person who had seen such a monstrosity during the whole history of the human race. Indeed, the assertion in question would have a much better chance of being believed than would the story told by the molecule which had lost an electron. For a molecule would, on the average, have to meet fifty thousand million million other molecules before finding one that had lost an electron; and if you could have lived long enough to have met all the people who have ever lived in your search for the two-headed man, you would probably have met less than a million million people.

We may view the matter from another angle. The charged molecules in the air attract one another and so are continually coming together and neutralizing one another's charges. It is only because electrons are being continually torn from the molecules of the atmosphere that all of the supply of charged molecules does not disappear. An important agent responsible for tearing the electrons from the molecules of the air is the cosmic radiation which comes to us from outside of our atmosphere. In order to account for the maintenance of the observed number of charged molecules in a pure atmosphere it is necessary to suppose that in each cubic inch about twenty or thirty molecules have an electron torn from them each second; and as a matter of fact, we know that the cosmic radiation contributes considerably to this result. But think what an exceedingly rare phenomenon this catastrophe of the loss of an electron is from the point of view of the molecules themselves. It is as rare a catastrophe to the molecules as would be a murder in the realm of mankind if, with the population of the earth at its present value, only one murder were committed on the whole earth in three hundred years.

Most of the outstanding phenomena of modern physics are miracles from the point of view of the atom. The photoelectric effect, which is

responsible for the operation of the photoelectric cell, which in turn is responsible for the wireless transmission of pictures, is the ejection of an electron from an atom through the agency of light. We have been accustomed to think of an atom as a little solar system with electrons performing a kind of dance around a central nucleus. Now in the photoelectric effect, you must think of a light beam shooting into an atom and hurling one of these electrons out of the atom in some such manner as that in which we might suppose a flash of light from the depths of interstellar space to burst into our solar system and hurl the earth into outer darkness. "The latter idea is a fantastic one," you will say. True, but much less fantastic than the photoelectric effect would seem to an inhabitant of an atom if there were any inhabitants. For, even if we confine our attention to the atoms (they are atoms of potassium or caesium) which are on the sensitive surface of the photoelectric cell, we shall find about a hundred million million million of such atoms, and even with a strong photoelectric effect any one of these atoms would, on the average, suffer the catastrophe of the ejection of an electron only once in ten million seconds, that is, about three times a year. If you lived on an atom and maintained that the photoelectric effect had ever occurred, you would certainly be in danger of being put in an atomic lunatic asylum.

I could go on in this way showing that most of the interesting phenomena of physics are miracles from the point of view of the individual atoms. I could go on citing countless illustrations of this kind, and I could talk for a long time on tracing their implications. However, the matter which I wish to stress is illustrated by the following considerations: that plants grow, that animals can see, is a result of the photoelectric effect or something very like it. If, a hundred years ago, I had formed the concept of this photoelectric effect in its fundamental atomic aspects and somebody had said to me, "Show me an electron coming off a piece of matter under the influence of light," I should not have been able to answer the challenge. I could only have pointed to the over-all effect of sunlight on plants and say that I could understand such effects if the photoelectric effect existed. If I had been confronted with the challenge a little later, I would possibly have performed a few experiments indicating that electricity seemed to be emitted by substances exposed to light. However, with my present knowledge of the influence of disturbing causes, the effects of moisture on insulating surfaces, etc., I realize that in that epoch, sometimes my experiments would have worked and sometimes they would not. Anyone who did not know anything about electrical insulation might well have been suspicious of my invoking moisture as an agent which upset my experiments. If I lived in a damp climate, my experiments would never have worked, unless by chance I was performing them on one occasion while the laboratory was burning down so that my apparatus was dried out. If I then

asserted that in order to make my experiments work and demonstrate the phenomena in question, it was necessary to burn the laboratory down during the experiments, I would certainly have been dubbed a fool or a charlatan. And now, today, with full knowledge of the conditions essential for success, I can actually count the individual electrons one by one as they come off a surface illuminated by suitable light.

Thus I think it is not logical to deny the existence or the possibility of existence of phenomena because of the relative rarity of their occurrence, nor, indeed, to deny their importance for this reason. Frequently in seeking verification of the primary phenomena, the conditions and mechanisms for bringing them to light are of vital importance.

What would any reasonable being have said one hundred years ago concerning the report that somebody in New York had heard the voice of someone in Germany? Would he not have regarded the phenomenon as a miracle? And yet, on this earth at that time was the wherewithal to make a radio transmission set and a receiving set. Take your radio apart and look at it. You will probably find much more complexity in the ornamentation of the dial than in what you find inside. Inside you will find a few glass globes containing wire, a few little boxes with sheets of mica inside, a few pieces of wire, and so forth. All of these elements of construction were very commonplace things a hundred years ago. Perhaps tungsten wire was not immediately available, but it was not far off, and something else would have served. In a sense, it is strange that in the whole 6000 years of man's civilization, nobody put these things together before.

I believe the statisticians will tell us that if you let loose a group of monkeys who play with what they find by accident, then once in an aeon these monkeys will by accident put together such things as make a radio set. Of course, there are so many things that can be put together that the chance of putting a radio set together is very small, unless there be some urge to do it. Even in the case of wireless, the urge came from previous doings, going back step by step to the times of Lodge and Hertz. And for 6000 years, nobody had thought of trying an experiment such as Hertz tried. He only tried it to verify some points about Maxwell's theory which evolved from certain experiments of Michael Faraday. The materials necessary to perform Faraday experiments have certainly existed for thousands of years, but there seemed no reason to try such experiments, and anybody who had tried them would probably have been dubbed a lunatic for his pains. So foresight makes man a lunatic while hindsight makes him a genius.

In the days which have passed, and particularly in the last three-quarters of a century, enormous progress has been made in understanding the physical universe. I use this word "understand" not in the sense of any ultimate understanding, such as the naive student of science seeks, an understanding in which he hopes to find the workings of the

universe as the offspring of laws which would be obvious to anyone. I fear that he who seeks this kind of understanding is like one who, seeing the moon behind a hill, travels to the hill only to find it is behind the hill beyond. By recognizing an understanding in our knowledge of the physical universe, I refer to a power to see a consistency of activity in the doings of the various parts, a consistency which can be expressed in mathematical terms even to the point of predicting what may reasonably be expected to occur under new circumstances not divorced too far from the circumstances of our past experience. I am much more thrilled by a realization that the design is such that out of a reasonably simple formulation of principles the richness of the universe is born, than I would be by some naive contentment in the belief that the principles are what might be expected.

In the lecture which I gave here two years ago, I stressed two points. The first was the extraordinary cleverness of the ways in which the principles were utilized to provide for all the needs of a complex universe, a cleverness which any engineer would envy, even if he believed himself to be the greatest engineer of all time. However, the second point involved in the creation of the *laws* themselves, the laws necessary to result in the observed possibilities, revealed a degree of cleverness far greater than that involved in the development of their consequences. Cleverness of this kind is something never demanded of the mortal engineer who starts with his laws already given. If, at any point in the study, I am to introduce the concept of a Creator and marvel at His powers, this is the point I would choose.

And today, encouraged as we may be by our success in understanding the workings of the physical universe, we are yet faced with the great problem of life and of human life in particular, its meaning, its purpose, and its goal. Any attempt to inquire into this matter, and particularly to inquire into any sequel which there may be to mortal life, invites criticisms comparable with those which faced Copernicus when he seemed to attempt a study of that which, according to the canons of the day, was a matter only for Divine Providence. Many who avoid criticism on the basis of theological considerations will, nevertheless, turn aside with a kind of angry disapproval suggestive of the fact that the would-be student of these matters is going crazy. And yet, if in the next ten years, some significant light should be shed on this dark territory of the unknown, I doubt whether the shock to our materialistic nature would be as great as that which would have been caused seventy-five years ago by a sudden view of the *future* of that day, in which the marvels of atomic science were suddenly brought to the eye of mankind. While all physicists twenty-five years ago talked of atomic energy, I feel confident that many of them regarded its actual release by man as something different from all his achievements of the past, something in which there were natural barriers which he could never

surmount. Even the recognition that the sun's heat was probably provided by atomic energy was staggering enough, and the mind was only relieved from the terror of invoking the miraculous by the thought that the sun was very big and very far away, was an astronomical body out of the control of man, and a place where the normal might well merge into the miraculous as part of the whole evolution of the universe.

I feel that in approaching the unknown in the matter of man's place in the universe, it is first necessary to divorce the considerations from anything to do with religion. The intent here is not to deny or even to voice any criticism of orthodox religions, but to regard them as something apart from the study in hand, and something which need not be brought into the domain of such study. The danger of bringing religion into the matter stems from the fact that if we do so we are apt to encumber the considerations with extraneous, and frequently controversial matters, which vary from creed to creed and need really play no part in the study. I may say that this view has been voiced strongly by the late C. N. M. Tyrrell, who was President of the Society for Psychical Research for seven years before his death in 1952. In citing this plea, I again call attention to the difficulties encountered by early men of science such as Galileo in studying the laws of astronomy. I do not think that today anyone would maintain that the question of whether the earth was flat or round need be a deciding factor in the real working aspects of religion. I do not believe that the noble principles advocated in the Sermon on the Mount rest their validity in any way upon the flatness or roundness of the earth. Yet the orthodox belief that the earth was like a box was regarded so firmly as a part of the religious faith of the day that any assertions about astronomy which denied it were regarded as at variance with the true faith and unacceptable.

Without, therefore, uttering one word of criticism about the essentials of any religious faith, it would seem appropriate to study matters without reference to religious principles. If, in the course of the study, some of the principles of religion become revealed from the study itself, then their wedding with the faith as born of religion will be all the stronger.

In my lecture delivered here two years ago, I cited what I deem as strong evidence that the universe has the character of an extraordinarily well-planned structure. I maintained that the further possibility inherent in the supposition that there was a supernatural being who planned it invoked grave difficulties concerned with the very meaning of our words. However, direct observation reveals a condition in which on the whole, and as far as mankind is concerned, a development towards an ever-increasing richness of happiness occurs. I suggested, as a thing on which to pin one's faith, the belief in this condition and I implied that it was well to distill out of this whole situation a purpose for this uni-

verse, that purpose being the evolution of a universe in which happiness could come into being. Without such a purpose, I voiced a failure to envisage any reason for a universe at all.

And so, without any question of how the universe came into being, we recognize its existence as a structure showing the characteristics of planning, and with a development toward a situation in which beings who can experience happiness exist. If somebody points out that happiness is not universal and that many cruel things happen, I admit that I am not astonished. This is simply evidence that the universe is not yet perfect as regards the quest of happiness. The fact that the goal seems to come nearer as time approaches is encouraging, however.

And so, as I view development, I see first the dead earth of a billion years ago. I do not believe that the rocks therein were very happy. Then I see the beginnings of life. I do not feel that there was much happiness in the primitive forms of unicellular life, although there may have been some. Finally, I see man evolve, and I see his potentiality for happiness increase with his development. Yet this happiness never achieves anything like my concept of the maximum possible in any individual. Am I to believe, however, that in man's so-called death that germ of happiness which used his mortal frame in which to exploit itself must come to an end? Of course, I cannot be sure of anything, but if such is the case, what a waste! Even such understanding of the universe as I thought I had evaporates, for I see this marvelous development of creation, with its clever laws and its skillful utilization of these laws to the development of greater richness culminating in the appearance of man, and his potentialities. Then comes this silly thing at the end. I have confessed to no great love for consistency, but even as an opponent of consistency, I cannot very well swallow the enormous inconsistency between the preparations for a purpose and the complete evaporation of the purpose at some particualr stage which we call the death of the individual. It is much easier for me to believe that something happens which I cannot yet understand, then to believe that nothing happens.

And so, if I should try to understand a little of this unknown territory which lies beyond mortal life, and to do so in the spirit of a scientist, how am I to proceed?

It would naturally be a presumption to attempt the formulation of a complete program for this task, but it may not be too great a presumption to draw upon what experience has taught us in our researches in the domain of the physical world as a starting point to sense the direction which the program may take. In particular, I start with some confidence, born of my experience as a man of science, in extrapolating, at least for a short distance, the apparent intent of the past into the realms of the future.

In the first place, as I think I have already demonstrated, there is nothing in our science of today to make any extension to include the unknown

a matter antagonistic to that science. However, experiences of the past have taught us that delay in progress in science itself has resulted from resistance to the acceptance of some element of structure not heretofore used. Physics affords an example in the resistance to the incorporation of a neutral particle—the neutron—in the scheme of atomic physics. So wedded had we become to the complete electrical structure of matter that any suggestion of the participation of a neutral particle struck at the very roots of something which it seemed desirable to preserve. It is true that neutrons had been thought of and, indeed, postulated before their actual discovery, as partners in the relationships of atoms between themselves; but it was not until their direct discovery that real advances were made through recognition of these entities as things existing in their own right as equal partners with the proton and the electron and not as mythical abstractions performing some mysterious and ill-defined functions. Then when courage had grown to the point of such a recognition, the step towards the neutron's assumption of a role as one of the three constituents of all matter was immediate. No longer did neutrons hide in the realm of speculative theory, to be called upon for service only as a last resort. They came to be recognized as playing a part so fundamental that nothing done by the protons and electrons, which formerly owned the show, was now done without their sanction.

I feel that in the affairs of man's mortal life, and possibly in his later existence, the concept which now occupies that position which the neutron occupied thirty years ago in the affairs of atomic physics, is that little-understood element, heard of only in theology, or in the expression of artistic creations, that shadowy thing, spoken of with bated breath and almost with awe and even terror, that we call the "Soul" of man. Even the most staunch materialist must feel at times that there is something about him which is different from what he can construct from the material elements of science. As a materialist, he probably resists the intrusion of this unwelcome entity. It seems to have no place in what he has come to believe as the building blocks of the physical world.

Those vague feelings of the part played by the soul in everyday life are analogous to the feelings of the role of the neutron when it was viewed as a vague representative of something not yet understood, and invoked to harmonize certain relationships between the atoms. The disembodied soul, the souls of those who have passed on, are perhaps in some way analogous to the neutrons after man found ways to release them from their partners in matter, and reorganize them in the richness of their own attributes.

Since the beginning of time, neutrons have played their individual roles in the stars; and, indeed, modern astronomy teaches us that at the birth of our universe some four or five billion years ago, they were the only material particles in existence. Yet, it is only within the last few years that science has found ways to observe them directly. Even to-

day, they are among the hardest of the atomic entities to observe as every nuclear physicist knows. If, therefore, the skeptic has doubts about the meaningfulness of the disembodied soul, because no evidence strong enough to satisfy everybody has been found to warrant the belief that mortal man can become conscious of, communicate with, or, to use a laboratory physicist's term, detect such an entity, then I point to an epoch within the lifetime of practically all of you who are now present, an epoch in which the same criticism might have been made regarding the reality of the neutron.

Of course, I need hardly remind you of the existence of an enormous amount of documentation concerning phenomena in which claims as to communion between the physical universe and the unknown universe are revealed. Of these I do not feel competent to speak, since I have not studied them. I can only remind you that many men of acknowledged care in judgment have in various degrees found conviction in some of the phenomena. I refer, for example, to Sir William Crookes, Sir Oliver Lodge, Lord Rayleigh and Earl Balfour.

As part of the custom to relegate to the ultra-mysterious all things concerned with the matters of which I am now speaking, there is a tendency, even among those who accept the existence of an afterlife, to form all sorts of opinions as to the states of existence of departed individuals, opinions involving concepts ranging from hell, through purgatory to Heaven. I will confess that if these matters should ever bow to successful investigation along the lines of the scientific investigations of the past, I, for one, would not be surprised to find much less difference between those of the unseen world and the rest of us than is generally supposed. Just as the neutron retains certain of the characteristics of protons, electrons and neutrons and of their conglomerations which we call atoms, the characteristics of mass, the power to bind itself to other particles and influence their activities, and so on, so would I be not astonished to find the inhabitants of the unseen world retaining many of the characteristics of mortals. I should expect changed features, tending presumably to a higher state of development and a higher potentiality for happiness, if our thesis as to the purpose of the universe is correct.

And now, while I have maintained that the study of these matters is simplified if it is made without reference to theology, the question as to the place of a deity will inevitably come up continually. That the universe is a structure showing, in outstanding degree, those elements which we associate with planning, is an experimental fact, and requires no faith or theological doctrine for its acceptance. Even an out and out atheist cannot deny it. However, the separate question of whether it is meaningful to postulate the existence of a planner leads to endless philosophical difficulties concerned with the origin of the planner, with dogmas and beliefs as to how to gain favor with the planner and so

forth. And yet, at any stage of his development, man stands, as on a seashore, with tried experience in the form of land which he knows and mystery in the wide expanse of the ocean, which he does not know, but which he yet feels is powerful to influence his destiny. If he is willing to accept that the unknown is a culmination of the known, he may find it convenient to fuse all of the characteristics of the former into the concept of purpose of a being, so that his code of ethics in life, his religion, if you will, his hopes for the future are concepts cloaked about this being as an ideal. If he inquires what part he has power to play in influencing his own destiny and that of others like himself in that realm where the cleverness of his brain and the strength of his muscles no longer suffice, then will he naturally turn to those forces of non-material nature which control the activities of what we call the soul. How to use these forces, it remains for him to learn; but there is much evidence for the belief that the expression of an intense desire, particularly in critical situations, brings results. The belief in the process involved in the concept of the "faith which moveth mountains" is not without foundation. And so, the utilization of an expression of a desire, be it in the form of profound meditation as practiced by the holy men of the east, or in prayer as practiced in one form or another by all men, is something which may be calculated to achieve success.

As I say these things, I think of the many who would think the ideas involved fantastic; and yet, I am convinced that many of these will go to their places of worship and utter the prayers placed before them. In doing so, perhaps without too strong a conviction as to their potentiality, they may become the most astonished of all people if their prayers appear to be answered.[5]

And so, in all humility, and without any assertive stand as to the meaning of creation and of our place in it, I can at least express the

[5] The idea involved in the attempt to harmonize the purpose of the unknown and man's reaction to that purpose through the imagery of a Deity may be illustrated by an appeal to science itself. The first illustration is very simple. I place a candle before a mirror. The light of the candle after reflection from the mirror is a matter of interest to me. If I think of it in the form of its reflection from various portions of the mirror, I have a picture rather difficult to comprehend. I know that when all is done, however, the light comes to my eyes from the mirror *as though* it had come from another candle behind the mirror. There is, in actuality, no candle behind the mirror, and yet, by its invocation as an image, my power to utilize and understand the light coming from the mirror is enhanced. It may be objected that, in this illustration at least, there is a candle somewhere in the picture. In order to remove this objection, I will take another, which, alas! is of a rather technical nature, so that only the scientifically trained will understand it.

If we consider a function ψ obeying Laplace's equation within a surface S, then the value of ψ at any point within S may be calculated as the potential due to a distribution of dipoles over the surface, and a distribution of charges. The moment per unit area of the dipoles at any point on the surface is to be taken as the value of ψ at that point, while the surface density of charge is to be taken as the normal gradient of ψ at the point. Now in this illustration, nobody contends that the dipoles and charges are actually present.

thoughts which I *wish* might be true. And in this spirit, I envisage that out of the voids of space there came a universe—a structure of intelligent design, anticipating in its youth the glories of its maturity. If I would believe anything as to the purpose of this universe, I would wish to believe that all was a preparation for the bringing into existence of something which is worth while. The inanimate universe had no *immediate* purpose—the stars of the heavens have no regard one for the other, except in their mutual control through what we call the laws of science. Such a purpose would not in itself seem to constitute a worthwhile end.

But if all of this development of structure is a preparation for the existence of something which, in the absolute sense may be thought of as good, then its purpose is guaranteed. This purpose began to become achieved when life appeared, and a doorway to its culmination was opened when a concept we call happiness began to shine out of the void, for the seeds of happiness exist only in the potentialities of the souls of living beings. Each new soul, born of the void, becomes an entity which exists forever, to the end of its own continued joy and the enrichment of the joy of its fellows. Perhaps that experience in accommodation in the period which we call the span of mortal life is but an apprenticeship—an apprenticeship in which all the little corners of roughness become smoothed over for the more perfect realization of the ideal, the ideal of happiness, an ideal which is perhaps the only thing with absolute meaning in all philosophy—an ideal whose realization is an achievement of which even a God might be proud!

RESIDUAL STRESSES IN HEAVY-WALL CYLINDERS *

BY

J. H. FAUPEL [1]

ABSTRACT

The amount of residual stress resulting from the autofrettage of steel cylinders appears to be related to the hardness and/or structure of the steel employed. Results presented show that an annealed alloy steel cylinder autofrettaged to raise its elastic-breakdown pressure significantly did not indicate residual stresses sufficient to account for the measured increase in elastic-breakdown pressure. On the other hand, residual stresses established by thermal shock when measured in the same fashion are sufficient to account for the change in elastic-breakdown pressure measured in a pressure test regardless of the hardness of the material.

NOMENCLATURE

The following nomenclature is used in the paper:

A = cross-sectional area (variable), sq. in.
A_0 = initial cross-section area, sq. in.
E = modulus of elasticity, psi.
R = cylinder wall ratio c/a
a = bore radius of hollow cylinder, in.
b = radius to plastic-elastic boundary in cylinder, in.
c = radius to outside of cylinder, in.
d = differential sign
p_r = pressure to cause yielding to radius r in cylinder, psi.
p_y = elastic-breakdown pressure in cylinder, psi.
r = variable radius in cylinder, in.
s_h' = residual hoop stress in cylinder, psi.
s_r' = residual radial stress in cylinder, psi.
s_y = yield strength in tension, psi. (0.01 per cent offset)
s_z' = residual longitudinal stress in cylinder, psi.
ϵ_h = hoop strain in cylinder, in./in.
ϵ_z = longitudinal strain in cylinder, in./in.
μ = Poisson's ratio; also symbol for "micro" as in microinches
α = $(\epsilon_z + \mu\epsilon_h)$, in./in.
θ = $(\epsilon_h + \mu\epsilon_z)$, in./in.

INTRODUCTION

In an earlier paper (1) [2] results were presented of several tests involving the effect of thermally induced residual stresses on the characteristics

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[1] Engineering Research Laboratory, E. I. du Pont de Nemours & Co., Inc., Wilmington, Delaware.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

of heavy-wall cylinders. Some of these results will be referred to in the present discussion; however, in this paper, the principal topic concerns residual stresses in "autofrettaged" heavy-wall cylinders. At the Engineering Research Laboratory of the Du Pont Company, perplexing phenomena regarding dilation characteristics of soft steel cylinders prestressed by autofrettage have been observed. Discussion of these observations forms the basis for this paper.

Theory of Autofrettage

The fundamental basis of autofrettage lies in the inability of nonuniformly plastically deformed metal to return to its original unstressed state following release of the autofrettage pressure. Amount of autofrettage is frequently expressed on a percentage basis such as 10, 50, or 100 per cent. This percentage refers to the degree of residual stress left at the bore of the cylinder and not to the amount of the cylinder wall plastically deformed. For example, 100 per cent autofrettage means that, on release of autofrettage pressure, the bore is left with the maximum theoretical degree of compressive residual stress; 100 per cent overstrain of the cylinder wall means that all of the wall has been plastically deformed. Thus, for a large enough cylinder 100 per cent autofrettage is possible by an overstrain of 10 per cent or less.

It is assumed that the material is perfectly plastic and incompressible, that the properties are the same in compression as in tension and that a Bauschinger effect as observed in tension and compression tests does not manifest itself in a field of combined stress. Finally it is assumed that the distortional energy of a cylinder under internal pressure is proportional to the distortion energy as measured in a tensile test; mathematically,

$$s_y^2 = s_h^2 + s_r^2 + s_z^2 - s_h s_r - s_r s_z - s_z s_h. \qquad (1)$$

Using the above relationship of stresses it can be shown that there is a theoretical mechanical maximum limit of autofrettage (that is, metallurgical effects such as strain aging are not considered). Since, in a cylinder the radial residual stress is zero at the bore, the highest stress system that can be accommodated is given by the above equation with s_r reduced to zero, and the other terms expressed in terms of pressure and wall ratio accordingly. A fully plasticized cylinder of wall ratio ≤ 2.22 will, theoretically, show no reyielding effect. For cylinders of wall ratio > 2.22 reyielding should occur on release of pressure if the pressure is greater than twice the initial elastic-breakdown pressure. Actual residual stress distribution for cylinders in which reyielding has occurred can be computed from equations given by Prager and Hodge (3). Reyielding, it should be noted, does not decrease the equivalent residual stress distribution at the bore of the cylinder; it does provide

a limit of stress which cannot be exceeded except by a change in material properties brought about by strain aging or some other metallurgical effect.

Some Problems in Autofrettage Theory and Practice

The principal assumptions involved have already been mentioned; certain of these assumptions, such as the condition of perfect plasticity, may introduce errors since many steels work-harden at a rapid rate.

Additional difficulties are experienced in connection with the metallurgical aspects of the problem. For example, there is evidence that residual stresses in autofrettaged steels can be determined by the Sachs boring-out method only if the steels have a hardness of over about 25 Rockwell C; there is evidence that a "stabilization" heat-treatment, consisting of heating an autofrettaged cylinder at some temperature around 500 F., has a beneficial effect for some steels but is of no apparent benefit for other steels. In addition to these it is known that certain steels contain heat-treatment residual stresses or may "strain age" and it is reasonable to expect that such steels might be unpredictable from the point of view of elastic range strength following autofrettage. If cyclic loads are involved it is reasonable to expect some influence of cycling on the properties of the material and on the residual stress pattern set up in the cylinder wall by autofrettage; thus, even though autofrettage may raise the apparent static elastic strength it cannot be said *á priori* that the same is necessarily true for fatigue loading. Finally, there is no evidence concerning the condition of "overfrettage." Are undesirable effects introduced by reyielding? Can fatigue failures initiate within the wall of an autofrettaged cylinder at locations of high tensile stress? These are a few of the problems that come to mind.

Specific Problem Investigated

It has been demonstrated that the elastic-breakdown and final bursting pressures for heavy-wall cylinders subjected to internal pressure can be experimentally defined by reference to the pressure-strain curve obtained during pressurizing (1). The elastic-breakdown pressure is noted as the end of the straight-line portion of the pressure-strain curve with origin at zero pressure and strain. It can be predicted by use of the following equation providing that tensile test data for the steel used for the cylinders are available and providing that the magnitude and direction of any bore residual stresses are known.

$$p_y^2\left[\frac{R^2}{R^2-1}\right]^2 + p_y\left[\frac{R^2}{R^2-1}\right]s_h' + \tfrac{1}{3}\left[(s_z')^2 + (s_h')^2 - s_h's_z' - s_y^2\right] = 0. \quad (2)$$

The bursting pressure is the maximum internal pressure sustained by the cylinder and it can be predicted by a method outlined in Ref. 1. The statistical validity of each of these formulas has been established and they are correct 90 per cent of the time to less than ±15 per cent of the measured values. Both elastic-breakdown and bursting pressures are important engineering quantities since the former indicates the maximum range of completely linear elastic behavior within which accurate calculations can be made of stress and deformation, and the latter determines the factor of safety. Between these two pressures, however, lie the various pressure levels used for prestressing cylinders by the autofrettage process. In this process the appropriate pressure

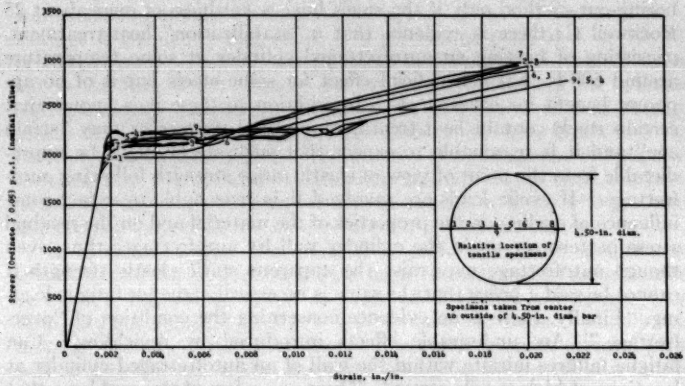
Stress (Offset = 0.05) p.s.i. (nominal value)
Strain, in./in.
Relative location of tensile specimens
4.50-in. diam.
Specimens taken from center to outside of 4.50-in. diam. bar

FIG. 1. Tensile stress-strain curves for annealed Bethlehem Gun Steel.

level used for prestressing depends on the wall ratio of the cylinder and the strength properties of the material; consequently, it is desirable to know how these factors combine to set the pressure level and also to know what residual stresses are left in the cylinder wall following release of pressure. This is important because for the same factor of safety based on bursting, the range of linear elastic operation of a cylinder can be doubled, theoretically, by suitable autofrettage.

In order to determine how far through the cylinder wall overstrain should be carried in order to accomplish the desired autofrettage it was necessary to use the following equation which defines the pressure for various amounts of wall yielding.

$$p_r = \frac{s_y}{\sqrt{3}}\left[\frac{c^2 - b^2}{c^2} + 2\ln\frac{b}{a}\right]. \qquad (3)$$

The specific problem under investigation was therefore the experimental confirmation of Eq. 3 which predicts the plastic-elastic boundary. It

was also desirable to assess the residual stresses left in the cylinder wall after autofrettage. Various anomalies were observed during the course of the experimental work which will be described.

DISCUSSION

Material and Properties

It was believed that the material would have a significant influence on the results, consequently the decision was made to use a material having uniform properties through the section thickness; 4.5-in. diameter Ni-Cr-Mo-V (Bethlehem Gun Steel) [3] was selected. In order to avoid any complication that might result from the presence of residual heat-treatment stresses in the material, an annealing procedure was employed which consisted of soaking at 1525 F. ± 25 F. for 3 hr. followed by furnace cooling. This treatment is believed to have left the cylinders initially stress-free. Tensile tests were conducted on longitudinal specimens from nine locations across the cross-section of the bar and the results are presented in Fig. 1.

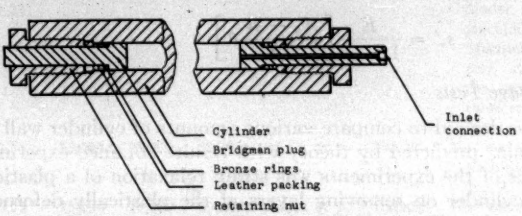

FIG. 2. Test cylinder assembly (general).

Cylinders and Pressure Tests

Tests were conducted on cylinders approximately 15 in. long. Details concerning the cylinder geometry are contained in Table I. The general set-up is shown in Fig. 2. Outside surface strains were obtained

TABLE I.—*Details of Test Cylinders.*[*]

Cyl. No.	i.d., in.	o.d., in.	Length, in.	Wall Ratio, o.d./i.d.	Theoretical Overstrain, %	Test Pressure, psi.	Remarks
130	1.500	4.125	30	2.750	25	40,000	
131	1.500	3.330	30	2.220	100	46,000	
131A	1.500	3.330	15	2.220	0	0	Used for Sachs test.
132	1.500	4.125	30	2.750	100	58,000	
133	1.500	4.125	30	2.750	50	50,000	
134	1.000	4.125	18	4.125	10	40,000	
134–1	1.519	4.125	18	2.720	—	—	After Sachs test on Cyl. No. 134, quenched from 1250 F.
134A	1.000	4.125	15	4.125	16	45,000	Heated at 650 F. after autofrettage.

[*] Annealed Bethlehem gun steel.

[3] 0.35% C, 0.73% Mn, 0.48% Ni, 1.39% Cr, 0.13% V, 0.52% Mo, 0.20% Si, balance Fe.

from SR-4 electrical resistance strain gages at several locations on the cylinder. Strains were recorded for small increments of pressure, providing plots of pressure versus strain which were used in the correlative work. Further details are recorded in Ref. 1.

Residual Stress Test

Following the autofrettage treatment on a cylinder, a section at least 12 in. long was removed and residual stresses determined using the following equations by the Sachs boring-out procedure (2) as described in Ref. 1.

$$s_z' = \frac{E}{1-\mu^2}\left[(A_0 - A)\frac{d\alpha}{dA} - \alpha\right] \tag{4}$$

$$s_h' = \frac{E}{1-\mu^2}\left[(A_0 - A)\frac{d\theta}{dA} - \frac{A_0 + A}{2A}\theta\right] \tag{5}$$

$$s_r' = \frac{E}{1-\mu^2}\left[\frac{A_0 - A}{2A}\theta\right]. \tag{6}$$

Autofrettage Tests

If was desired to compare various amounts of cylinder wall yielding (overstrain) predicted by theory with results obtained experimentally. The basis of the experiments was strain relaxation of a plastically deformed cylinder on removing layers of the plastically deformed zone from the bore. Theoretically, when all of the plastically deformed metal is removed no further strain relaxation should occur; this can be observed by plotting relaxation strains (α and θ in the foregoing equations) against bored-out area. Thus, in the experimental work the plan was to autofrettage cylinders by various amounts of overstrain and determine the plastic-elastic boundary and residual stresses by the boring-out procedure.

A "stabilization" heat-treatment following autofrettage was not included in the present series of tests since the fundamentals of the stabilization mechanism are not clear and it was desired not to complicate the analyses with inclusion of such a heat-treatment. Stabilization may be a very important item, however, particularly if the autofrettaged steel is susceptible to strain aging which might offset any stress relief effects and even increase the material strength.

Results of Tests

The results are presented in Tables II and III. In discussing these data it is necessary to consider the individual tests in order, as follows:

(a) Cylinder No. 130, Fully Annealed Bethlehem Gun Steel, Overstrained 25 Per Cent Through the Wall

The pressure-strain data are recorded in Fig. 3. On the first cycle to the autofrettage pressure of 40,000 psi. determined by Eq. 3, the elastic-breakdown pressure [4] of 25,000 psi. was predicted using Eq. 2.

TABLE II.—*Results of Autofrettage and Residual Stress Tests.*

Cyl. No.	Wall Ratio, R	Elastic-Breakdown Pressure, psi.		Autofrettage Pressure, p_f, psi.	Special Treatment	Maximum Linear Behavior After Autofrettage, psi.	Test Results
		Observed	Calculated				
130	2.75	25,000	25,000	40,000	5 hr. at p_f	40,000*	Checked (approx.) results of recycle test after autofrettage and Eq. 3.
131	2.22	25,000	23,120	46,000	62 hr. at p_f	30,000	No correlation with autofrettage tests or Eq. 3.
131A	2.22						Cylinder tested for machining stresses. Machining did impart stresses, but the magnitude of these stresses could not be ascertained.
132	2.75	25,000	25,000	58,000	46 hr. at p_f	30,000	No correlation with autofrettage tests or Eq. 3.
133	2.75	25,000	25,000	50,000	70 hr. at p_f	Indeterminate	No correlation with autofrettage test or Eq. 3.
134	4.125	25,000	27,300	40,000	1 hr. at p_f	40,000*	No correlation with autofrettage tests or Eq. 3.
134–1	2.72						Following residual stress test on Cyl. No. 134, No. 134–1 was bore-quenched in water from 1250 F. Residual stress test then indicated bore compressive stress as previously found in Reference 1.
134A	4.125	25,000	27,300	45,000	4 hr. at 650 F., after ½ hr. at p_f	45,000*	No correlation with autofrettage test or Eq. 3.

* This is the maximum observed; it is not known whether or not linearity would be observed at higher pressures.

[4] The accurate prediction of elastic-breakdown pressure on the initial pressurizing is evidence of initially stress-free material.

TABLE III.—*Summary of Cylinder Behavior.*

Cyl. No.	Material and Treatment	Rockwell Hardness	Method of Stressing	Residual Stress Test Performance*	Pressure-Strain Performance after Stressing
130	B.G.S.—Annealed	90 B	25% Overstrain	Fair	Linear to 40,000 psi. after 5 hr., holding at autofrettage pressure of 40,000 psi.
133	B.G.S.—Annealed	90 B	50% Overstrain	N. G.	Nonlinear after 70 hr. at autofrettage pressure of 50,000 psi.
132	B.G.S.—Annealed	90 B	100% Overstrain	N. G.	Linear to 30,000 psi. after holding 46 hr. at autofrettage pressure of 58,000 psi.
134	B.G.S.—Annealed	90 B	10% Overstrain	N. G.	Linear to 40,000 psi. after holding 1 hr., at autofrettage pressure of 40,000 psi.
134–1	B.G.S.—Annealed	90 B	Bore Quenched	Good	Not determined.
131	B.G.S.—Annealed	90 B	100% Overstrain	N. G.	Linear to 30,000 psi. after 62 hr., at autofrettage pressure of 46,000 psi.
134A	B.G.S.—Annealed	90 B	16% Overstrain Heated at 650 F.	N. G.	Linear to 45,000 psi. first cycle.
110	AISI-1045, Q. and T.	25 C	Bore Quenched	Good	Linear to predicted pressure of 55,000 psi.
74	AISI-3320, Q. and T.	96 B	Quenched from Draw	Good	Linear to predicted pressure of 19,000 psi.
95	B.G.S.—Q. and T.	42 C	Bore Quenched from Draw	Good	Linear to predicted pressure of 71,000 psi.

* On some cylinders the Sachs boring-out residual stress test was conducted. A "fair" test means that the residual-stress test results were indicative only but in accordance with expected behavior. N. G. means that the test results were fictitious, due to machining stresses or other unknown complications. A "good" test gave results in accordance with expected behavior and gave correlative data. Q. and T. indicates steel quenched and tempered. B.G.S. indicates Bethlehem Gun Steel.

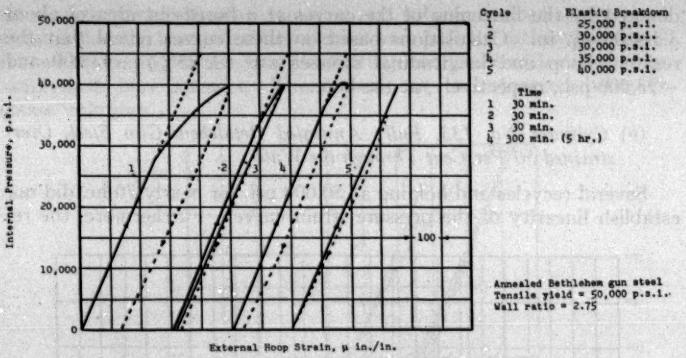

FIG. 3. Pressure-strain curves for cylinder No. 130, autofrettaged at 40,000 psi.

On the second cycle, elastic-breakdown was observed at 30,000 psi., whereas the expected value was 40,000 psi. As cycling proceeded and time increased at the autofrettage pressure, the expected value was approached but it was not until the fifth cycle, after 5 hr. of holding at 40,000 psi., that operation became linear to the autofrettage pressure. After establishing this linearity to the autofrettage pressure, a Sachs residual stress test was conducted. The strain-relaxation data recorded in Fig. 4 are very erratic although they do indicate a low overstrain as

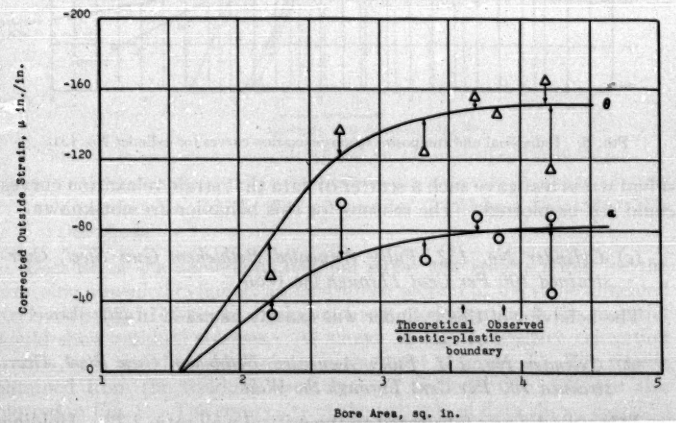

FIG. 4. Relaxation-strain curves for cylinder No. 130.

denoted by the flattening of the curves at a bored-out area of about 3.5–4.00 sq. in. Calculations based on these curves reveal that the residual hoop and longitudinal stresses are (± 25%) −43,000 and −23,000 psi., respectively, at the bore.

(*b*) *Cylinder No. 133, Fully Annealed Bethlehem Gun Steel, Overstrained 50 Per Cent Through the Wall*

Several recycles and holding at 50,000 psi. for nearly 70 hr. did not establish linearity of the pressure-strain curve. Furthermore, the re-

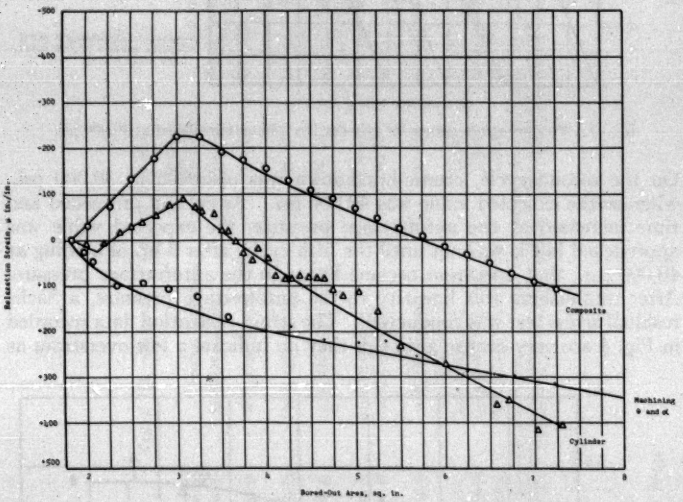

FIG. 5. Individual and composite strain-relaxation curves for cylinder No. 131.

sidual stress test gave such a scatter of data that strain relaxation curves could not be plotted. The reasons for this behavior are not known.

(*c*) *Cylinder No. 132, Fully Annealed Bethlehem Gun Steel, Overstrained 100 Per Cent Through the Wall*

The behavior of this cylinder was exactly as noted in (*b*), above.

(*d*) *Cylinder No. 131, Fully Annealed Bethlehem Gun Steel, Overstrained 100 Per Cent Through the Wall*

This cylinder was fabricated to the critical wall ratio 2.22. Holding at pressure for 62 hr. did not establish linearity of the pressure-strain

curve up to the autofrettage pressure and subsequent boring-out tests revealed that the bore relaxation strains were positive rather than negative, which would indicate that autofrettage induced tensile rather than compressive bore stresses. The reasons for the observed behavior remain unknown.

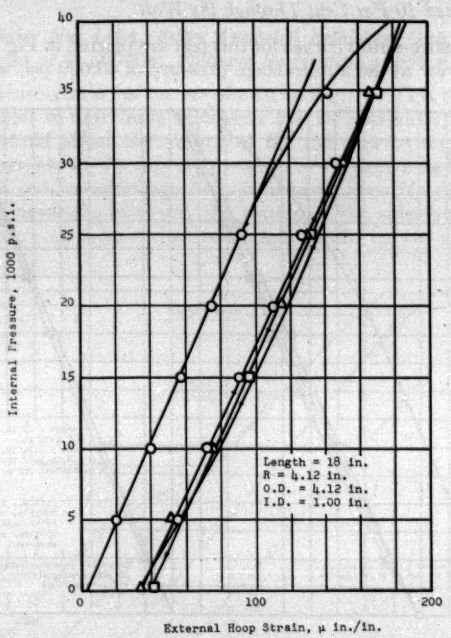

FIG. 6. Pressure-strain curves for cylinder No. 134 autofrettaged at 40,000 psi.

(e) *Cylinder No. 131A, Fully Annealed Bethlehem Gun Steel, No Overstrain*

Because of the anomalous residual stress test results noted for the foregoing annealed cylinder, an unstrained section of the same annealed steel was submitted to the boring-out test to determine if the material would show residual stresses. As shown in Fig. 5, positive relaxation strains were noted as machining (boring-out) progressed. The results obtained from the residual stress test on Cylinder No. 131 are also plotted in Fig. 5. The composite of the two sets of data shows negative relaxation strains near the bore of the cylinder, which, when interpreted

in terms of stress (Eqs. 4 and 5) checks theory quite well. However, it is believed that this result is at least partly fortuitous since only the bore residual stress checked theory.

(f) Cylinder No. 134, Fully Annealed Bethlehem Gun Steel, Overstrained 10 Per Cent Through the Wall

The pressure-strain curves for this test are plotted in Fig. 6. Elastic, linear behavior to the autofrettage pressure of 40,000 psi. was noted on

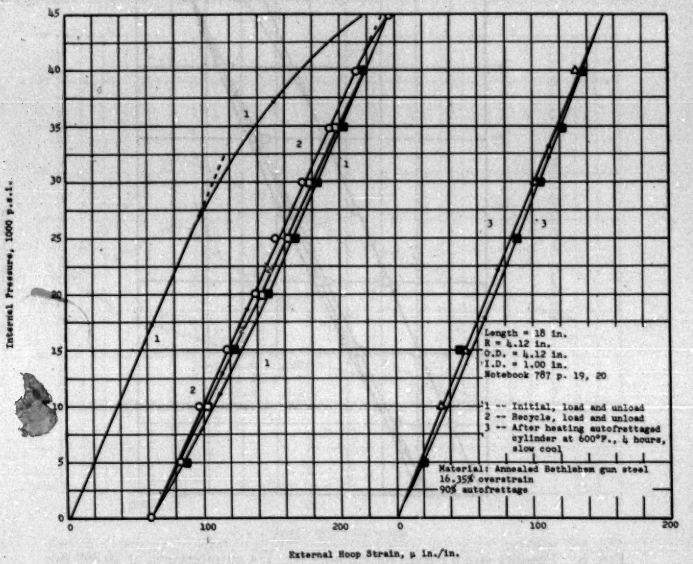
Internal Pressure, 1000 p.s.i.
External Hoop Strain, μ in./in.
Length = 18 in.
R = 4.12 in.
O.D. = 4.12 in.
I.D. = 1.00 in.
Notebook 787 p. 19, 20
1 -- Initial, load and unload
2 -- Recycle, load and unload
3 -- After heating autofrettaged cylinder at 600°F., 4 hours, slow cool
Material: Annealed Bethlehem gun steel
16.35% overstrain
90% autofrettage

FIG. 7. Pressure-strain curves for cylinder No. 134A autofrettaged at 45,000 psi.

the second cycle of pressurizing; this degree of linearity had not been previously noted. The residual stress test, however, indicated bore tensile residual stresses, the same as for Cylinder No. 131; consequently, as a check on the test, new strain gages were applied to the cylinder and the entire test set-up thoroughly examined. The same results were obtained again. After a few cuts on the cylinder the test was terminated and another check test made as follows: The partially bored-out cylinder (No. 134–1) was heated to 1250 F. and bore-quenched in water. A subsequent residual stress test on this newly processed cylinder indicated compressive bore residual stresses as expected. This result is in con-

formance with the behavior noted for various thermally stressed cylinders reported in Ref. 1. As a further check on the test set-up, a cylinder of thermally stressed steel tested in Ref. 1 was located and retested; nearly identical results to those first obtained were noted, indicating that there was nothing irregular in the testing technique.

(g) *Cylinder No. 134A, Fully Annealed Bethlehem Gun Steel, Autofrettaged at 45,000 psi., Followed by Heating at 650 F.*

The pressure-strain curves are shown in Fig. 7. This test was conducted in order to determine whether a special post-autofrettage heat-treatment would affect the ability of the cylinder to respond to the residual stress test in the expected manner. As shown in Fig. 7 subsequent to the post-autofrettage heat-treatment, linearity existed to the autofrettage pressure; however, the results of the subsequent residual stress test were so erratic that relaxation strain curves could not be plotted.

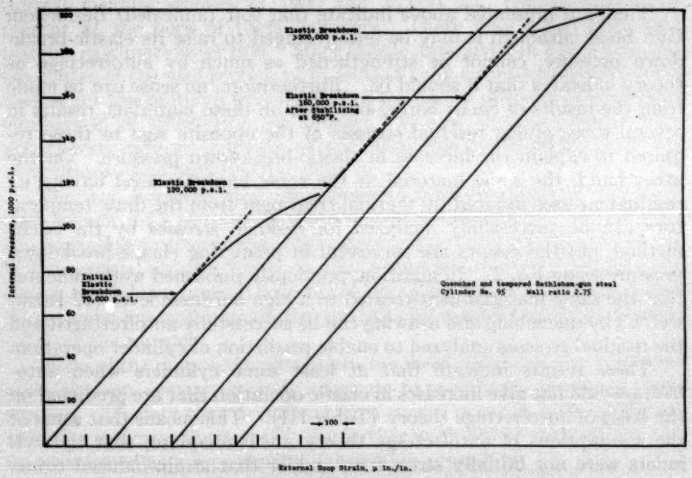

FIG. 8. Pressure-strain curves for heavy-wall cylinder showing influence of reyielding and stress relief on elastic-breakdown pressure.

Results of Previously Published Work

In order to indicate that these results are not characteristic of all materials and/or heat-treatment, an example of the opposite extreme of success in autofrettage is presented from a previous publication (1). Figure 8 shows the pressure-strain curve for a 2.74 wall ratio Bethlehem

gun steel cylinder (No. 95) heat-treated to a hardness of 42 Rockwell C by quenching and tempering. Boring-out tests indicated no macroscopic residual stresses due to heat-treatment, and Eq. 2 predicted an elastic-breakdown pressure of 70,800 psi. The measured elastic-breakdown pressure was 70,000 psi. The cylinder was autofrettaged by applying an internal pressure of 200,000 psi. for 4.5 hr. Following the pressurizing, the cylinder was given a stabilizing heat-treatment by holding for 3 hr. at 650 F. Recycling four times to 200,000 psi. established that the cylinder operated elastically up to at least the autofrettage pressure.

In addition to the result given above, reference is also made to numerous tests where residual stresses were introduced at the cylinder bore by thermal treatment alone (1). In all these cases prior determination of residual stresses by the Sachs method on similarily treated cylinders enabled the prediction of elastic-breakdown pressure.

Discussion

The data presented above indicate that soft (annealed) Bethlehem Gun Steel, although it may be autofrettaged to raise its elastic-breakdown pressure, cannot be strengthened as much by autofrettage as theory indicates that it should be. Furthermore, no sense can be made from the results of Sachs boring-out tests on these materials, results in several cases giving residual stresses of the opposite sign to those required to explain the increase in elastic-breakdown pressure. On the other hand, the same material at the same hardness level having its residual stresses induced by thermal treatment from the draw temperature can be successfully analyzed for residual stresses by the Sachs method and the results are successful in predicting elastic-breakdown pressure using Eq. 2. In addition, previously published work indicates that the same material heat-treated to a high hardness level (42 Rockwell C) by quenching and drawing can be successfully autofrettaged and the residual stresses analyzed to enable prediction of cylinder operation.

These results indicate that at least some cylinders when autofrettaged do not give increases in elastic operation that are predicted on the basis of autofrettage theory (Table III). This means that some of the assumptions of autofrettage theory are inadequate, that the cylinders were not initially stress-free, and/or that strain-induced transformations in the material do occur. Present theory relative to the prediction of thermally induced stresses that involve the complexities of volume changes in transformation, and the influence of composition, cooling rate, and stress on transformation kinetics is too uncertain to permit comparison with experiment.

The following comments should be made concerning the assumptions of autofrettage theory: (1) Work-hardening must contribute to the strengthening of cylinders upon overstrain. The amount of disagreement of experiment with theory from this cause has not been determined

and will certainly vary with the material and its heat-treatment. Those materials having the lowest yield-ultimate ratio will be most affected. (2) The assumption that the Bauschinger effect does not manifest itself in a field of combined stress can certainly be in error. The compressive yield strength of the bore fibers following overstrain establishes the incidence of reyielding upon release of the autofrettage pressure and in turn determines the level of residual stress that can be retained. Unidirectional tension and compression testing tells us that the Bauschinger effect is most pronounced in soft steel. This fact may be in line with the observed results.

Since an attempt was made in this work to start with initially stress-free cylinders, the possibility that the cylinders were not initially stress-free deserves some comment. These cylinders were furnace-cooled from the annealing temperature of 1525 F., and rings cut from the cylinder ends and radially split indicated no residual stresses of sufficient magnitude to be detected by this means. However, a boring-out test of an unstrained, annealed cylinder indicated that tensile hoop and longitudinal residual stresses of 1400 and 24,000 psi., respectively, were present at the bore of these cylinders. There may be at least two possible explanations of this. Since tensile data given in Fig. 1 indicate the center of the wall section to be weaker than either surface, furnace-cooling for this material may have been too fast to prevent the complete elimination of transformation stresses. It may also be possible that strains were induced by virtue of machining this soft material which led to fictitious calculated residual stresses.

The fact, however, that the calculated elastic-breakdown pressures were within ± 15 per cent of the observed value tends to suggest that the annealing treatment did relieve any major stresses present initially. If the residual stresses based on Fig. 5 are used in the calculation the elastic-breakdown pressure is indicated as 19,800 psi., which is more than 20 per cent low and outside the statistically established limit of reliability of the formula.

None of the proposed explanations for these results, or any combinations of them, appears entirely adequate to explain the results of these studies. The fact that deviations from theory occur in such significant amounts indicates the necessity for further work before autofrettage can be established as a reproducible fabrication procedure.

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(2) G. SACHS, "Residual Stresses, Their Measurement and Their Effects on Structural Parts," in "Symposium on the Failure of Metals by Fatigue," Melbourne (Australia) University Press, 1947, pp. 237–247.

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Printed Circuits for Industrial Control Equipment.—Printed circuitry and a new, simplified control system are features of a new line of full-wave Thy-mo-trol * electronic adjustable-speed drives, available at prices approximately 20 per cent lower than for previous models of the same type, according to the General Electric Company's Specialty Control Department.

Believed to be the first printed circuitry ever to be incorporated in industrial control equipment, the printboard panels can be visually inspected for circuit faults, G-E engineers said, since the panels are actually current-carrying diagrams. The panels can also be removed and replaced in a few seconds time, they said.

Since the new control circuit uses only a single miniature-type control tube, as contrasted with three conventional sized tubes in previous models, maintenance on the equipment is greatly simplified.

The new design has isolated a-c. control circuits that allow interconnection with a-c. drives without the use of additional relays. Power tube capacity is at least 40 per cent greater than the full load current of the motor with which it is normally used, they explained, providing ample margin for overload and assuring longer tube life.

The new design is available in two ratings, ¾ to 1-hp., and 1½ to 3-hp. full wave.

Basically an automatic electronic control for d-c. motor drives, the new Thy-mo-trol controls are designed to give stepless speed control from an a-c. power source over an 8 to 1 speed range, with higher speed ranges possible for special applications. Consisting of electronic sensing elements and an electronic power rectifier, it maintains very close speed regulation regardless of changes in load or line voltage, and limits starting torque to protect both drive and machine against overloads at all times.

Optional features available at extra cost as part of the Thy-mo-trol control line include push-button reversing, reactor loop control, jogging, and tachometer follower operation.

Other Thy-mo-trol drives, with conventional circuitry, are available in full- or half-wave models in ratings up to one-half horsepower. Full-wave precision models are also available in ratings from ¾ to 30 hp.

* Reg. trade-mark of the General Electric Co.

New Electronic Pressure Gauge.—A completely new Dynagage for measuring static and dynamic pressures and displacements under the most adverse temperatures and vibrations has been announced by Photocon Research Products, Pasadena, Calif. The new Model DG-400 with its integral power supply retains all the features of the original Dynagage with the size and weight reduced over 75 per cent.

Housed in a rigid aluminum casting, the Dynagage may be used with a complete new series of pressure pick-ups for measuring pressures up to 75,000 psi.

Outstanding features include a stable output of ± 15 volts into a high impedance load, frequency response from 0 to over 20,000 cps., cable lengths up to 1000 ft. for remote applications, and simplified tuning controls.

The new Dynagage is suitable for pressure studies in rocket and jet motors, auto and aircraft reciprocating engines, hydraulic systems, compressors, pumps, and explosive systems.

SYMMETRICAL THERMAL BENDING OF CIRCULAR DISKS WITH POWER FUNCTION PROFILE

BY

JACOB HERRMANN [1]

ABSTRACT

Steam- and gas-turbine disks are subjected to axial temperature gradients, especially when starting. A method is given in this paper for evaluating the resulting elastic thermal stresses when the thickness of the disk varies as any power function of the radius. The cases of a uniform disk and of one of composite form are also considered. The usual assumptions for thin disks are followed, and the elastic constants are assumed unaltered by thermal effects.

NOMENCLATURE

E = Young's modulus, psi.
ν = Poisson's ratio
α = coefficient of linear thermal expansion, per deg. F.
T = temperature at any point, deg. F.
z = distance from neutral surface to any point of disk reckoned positive downward, in.
r = variable radius, in.
t = thickness, in.
$D = \dfrac{Et^3}{12(1-\nu^2)}$ = flexural rigidity, lb.in.
c, n = disk profile constants
ϕ = slope angle of neutral surface of bent disk, positive when tangent runs upward with increasing radius
$\epsilon_r, \epsilon_\theta$ = respective radial and hoop strains, positive when tensile
p_r = radial tensile stress, psi.
p_θ = hoop tensile stress, psi.
M_r, M_θ = respective line intensities of radial and hoop bending moments taken positive when tending to make the disk bend concave upward, lb.in./in.

STATEMENT OF ASSUMPTIONS

Let us make the common assumptions for elementary elastic disk bending theory. The disk will be assumed to be thin, and the deflections should be small in comparison with the thickness. The relative rate of variation of thickness with respect to the radius must everywhere be gradual. Axial stresses will be neglected. The neutral surface of the unbent disk is to be flat. Lines originally straight and vertical will be assumed upon bending to become straight lines intersecting the axis

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of the disk. This last assumption, furthermore, implies a linear temperature variation through the thickness of the disk and an axially symmetric temperature distribution. The elastic constants will be considered uniform throughout the temperature range involved.

DEVELOPMENT OF THEORY

Under the assumptions outlined above, the stress-strain equations without allowance for thermal effects are shown (1) [2] to be

$$\epsilon_r \equiv z\phi' = \frac{p_r}{E} - \frac{\nu p_\theta}{E}, \tag{1}$$

$$\epsilon_\theta \equiv \frac{z\phi}{r} = -\frac{\nu p_r}{E} + \frac{p_\theta}{E}. \tag{2}$$

When there is a temperature variation, an additional strain αT results in each direction. Thus the stress-strain relations then become

$$z\phi' = \frac{p_r}{E} - \frac{\nu p_\theta}{E} + \alpha T, \tag{3}$$

$$\frac{z\phi}{r} = -\frac{\nu p_r}{E} + \frac{p_\theta}{E} + \alpha T. \tag{4}$$

Solving Eqs. 3 and 4 for the stresses, we find

$$p_r = \frac{Ez}{1-\nu^2}\left(\phi' + \frac{\nu\phi}{r}\right) - \frac{E\alpha T}{1-\nu}, \tag{5}$$

$$p_\theta = \frac{Ez}{1-\nu^2}\left(\nu\phi' + \frac{\phi}{r}\right) - \frac{E\alpha T}{1-\nu}. \tag{6}$$

Let the temperature at any point be

$$T = Kzr^m, \tag{7}$$

where K and m are constants. Various curves of axial temperature gradient *versus* radius can be fitted approximately by using combinations of terms of the form shown in Eq. 7 making m take on distinct values. If the increment of temperature from one face of the disk to the other is to be a polynomial in r, use consecutive integers for $(m + n)$ (definition of n with Eq. 17 below). Substituting from Eq. 7 into Eqs. 5 and 6 while using $z = t/2$, we obtain the following extreme fiber stresses:

[2] The boldface numbers in parentheses refer to the references appended to this paper.

$$p_{r,t/2} = \frac{Et}{2(1-\nu^2)}\left[\phi' + \frac{\nu\phi}{r} - \alpha K(1+\nu)r^m\right], \tag{8}$$

$$p_{\theta,t/2} = \frac{Et}{2(1-\nu^2)}\left[\nu\phi' + \frac{\phi}{r} - \alpha K(1+\nu)r^m\right]. \tag{9}$$

The line intensities of radial and hoop bending moments are, respectively,

$$M_r = \frac{t^2 p_{r,t/2}}{6}, \qquad M_\theta = \frac{t^2 p_{\theta,t/2}}{6}, \tag{10}$$

so that upon making the substitution

$$D = \frac{Et^3}{12(1-\nu^2)} \tag{11}$$

in Eqs. 8 and 9, we obtain

$$M_r = D\left[\phi' + \frac{\nu\phi}{r} - \alpha K(1+\nu)r^m\right], \tag{12}$$

$$M_\theta = D\left[\nu\phi' + \frac{\phi}{r} - \alpha K(1+\nu)r^m\right]. \tag{13}$$

Now the equation of equilibrium is deduced from that for ordinary bending without thermal effects (2) by merely dropping the shearing load term and thus obtaining

$$M_r + r\frac{dM_r}{dr} - M_\theta = 0. \tag{14}$$

But differentiating Eq. 12 with respect to r while remembering that the flexural rigidity D is now variable, we have

$$\frac{dM_r}{dr} = D\phi'' + \phi'D' + D\frac{\nu\phi'}{r} - D\frac{\nu\phi}{r^2} + D'\frac{\nu\phi}{r} - D'\alpha K(1+\nu)r^m - Dm\alpha K(1+\nu)r^{m-1}. \tag{15}$$

Substituting from Eqs. 12, 13, and 15 into Eq. 14 and then simplifying the result, we obtain the following differential equation:

$$r^2\phi'' + r\phi' + r^2\frac{D'}{D}\phi' - \phi + r\frac{D'}{D}\nu\phi = \frac{D'}{D}\alpha K(1+\nu)r^{m+2} + m\alpha K(1+\nu)r^{m+1}. \tag{16}$$

Now consider the power function profile

$$t = cr^n, \tag{17}$$

where c and n are constants. Then

$$D = \frac{Ec^3r^{3n}}{12(1-\nu^2)}, \qquad \frac{D'}{D} = 3nr^{-1}. \tag{18}$$

Substituting in Eq. 16, we have

$$r^2\phi'' + r(1+3n)\phi' + (3n\nu - 1)\phi = (3n+m)(1+\nu)\alpha K r^{m+1}, \tag{19}$$

which is the differential equation to be solved when the disk profile and temperature distribution are as assumed above. The general solution of Eq. 19 is

$$\phi = C_1 r^{q_1} + C_2 r^{q_2} + \frac{(3n+m)(1+\nu)\alpha K}{m^2+2m+3n(1+m+\nu)} r^{m+1}, \tag{20}$$

where C_1 and C_2 are arbitrary constants while q_1 and q_2 are the roots of the quadratic equation

$$q^2 + 3nq + 3n\nu - 1 = 0. \tag{21}$$

Differentiation of Eq. 20 yields

$$\phi' = C_1 q_1 r^{q_1-1} + C_2 q_2 r^{q_2-1} + \frac{(3n+m)(1+m)(1+\nu)\alpha K}{m^2+2m+3n(1+m+\nu)} r^m. \tag{22}$$

For a disk of uniform thickness, n vanishes thereby making Eqs. 19, 20, and 22 reduce, respectively, to

$$r^2\phi'' + r\phi' - \phi = (1+\nu)m\alpha K r^{m+1}, \tag{23}$$

$$\phi = C_1 r + C_2 r^{-1} + \frac{(1+\nu)\alpha K}{2+m} r^{m+1}, \tag{24}$$

$$\phi' = C_1 - C_2 r^{-2} + \frac{(1+\nu)(1+m)\alpha K}{2+m} r^m. \tag{25}$$

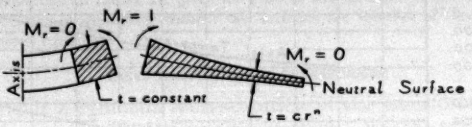
In a disk with either one of the profiles considered above pertaining throughout, the arbitrary constants are found directly from the end conditions. At a fixed edge, ϕ vanishes. At either a free edge or a freely supported edge, $M_r = 0$. In the case of a uniform disk continuous to the center, C_2 must vanish because otherwise ϕ as given by Eq. 24 would become infinite at $r = 0$. Once the arbitrary constants have

been evaluated, the extreme fiber stresses at any radius may be found from Eqs. 8 and 9.

When considering a disk of composite form like the one shown in Fig. 1, first make separate thermal solutions for the two regions using in each case zero edge moment M_r at the common edge and the actual applied M_r at the other edge. Next, make a solution for each part with no thermal effects while using $M_r = 1$ at the juncture and $M_r = 0$ at the other edge. Then the actual M_r at the juncture may be found from the condition that ϕ must have the same value on each side of that boundary. Finally, the true solution is obtained by superposition.

The variation in deflection between any two radii may be found by integrating ϕ in radians between the proper limits.

Let us now consider a steel disk of inside radius $= b = 2$ in., outside radius $= a = 10$ in., thickness at inner edge $= 1$ in., thickness at outer edge $= \frac{1}{4}$ in., $E = 30.10^6$ psi., $\alpha = 6 \cdot 10^{-6}$ in./in./°F., and $\nu = 0.3$. A



Note: Arrows with radial moments indicate positive directions.

FIG. 1. Regions of composite disk bent by unit M_r at juncture.

paper by Manson (3) gives some test results on axial temperature increments obtained on an actual turbine disk in operation. Using Manson's results as a guide, let us assume a face-to-face temperature increment $= (300 - 3r^2)$ °F. The principal quantities involved in the calculation are listed below, where the equations used in obtaining them are given in parentheses, and the subscripts for K and m pertain to the two terms in the expression for temperature increment. The chief data of interest are shown in Fig. 2. The stresses appear rather low. The bending would actually involve no stresses if the axial temperature increment were proportional to the disk's thickness. On the other hand, considerably higher stresses than indicated on Fig. 2 could arise from (*a*), a decidedly higher over-all temperature increment made plausible by Manson's tests and (*b*), a greater dissimilarity between the curves representing disk profile and face-to-face temperature increment.

c	1.817 (17)	m_2	2.861 (7), (17)
n	−0.861 (17)	q_1	3.148 (21)
K_1	165.1 (7), (17)	q_2	−0.564 (21)
K_2	−1.651 (7), (17)	C_1	$-15.93 \cdot 10^{-6}$ (20), (22), (12),
m_1	0.861 (7), (17)	C_2	0.00300 ($M_{r,a} = M_{r,b} = 0$)

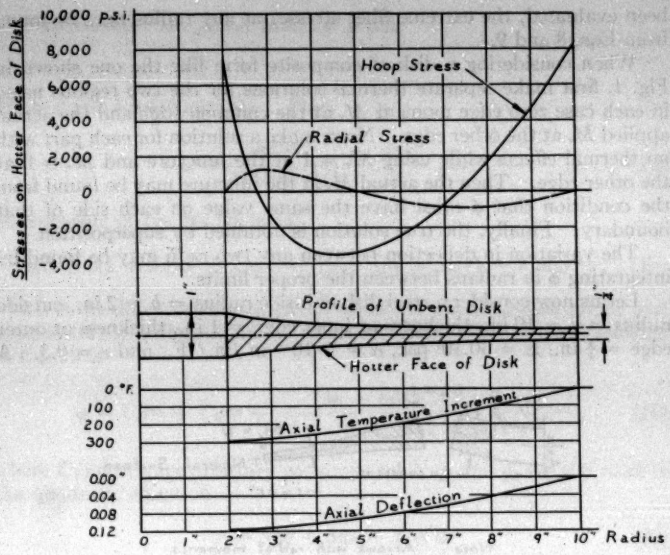


FIG. 2. Data of worked example.

Acknowledgment

I acknowledge my indebtedness to Dr. L. H. Lee, Professor of Engineering Mechanics at Notre Dame University for his valuable suggestive criticisms.

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LINEAR ALGEBRAIC COMPUTATION BY MULTI-WINDING TRANSFORMERS

BY

FREDERICK L. RYDER[1]

SYNOPSIS

This paper describes the behavior of a transformer having a plurality of windings mounted on a single core, and discusses applications in the automatic computation of linear algebraic expressions such as simultaneous equations and the like. The computing circuits are superior to prior ones in that they combine the following properties: they contain no amplifiers, or components of limited life such as vacuum tubes; they require no iteration, either manual or automatic; and they bear a close pictorial resemblance with the equations to be solved, thus simplifying the operating procedure. Actual experimental results are given for a set of simultaneous inequalities such as occur in linear programming theory; this includes the solution of several sets of simultaneous equations.

IDEAL MULTI-WINDING TRANSFORMER

Figure 1 is a symbolic representation of the transformer, which is intended for use in a single-frequency system. For the sake of definite-

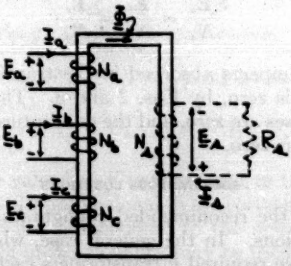

FIG. 1. Multi-winding transformer.

ness three windings are shown, although any practical number can be used. The number of turns per winding is N (with suitable subscript), the vectorial value of current in the different windings is $\mathbf{I}$, and the flux in the core, considered vectorially, is Φ. The N's are presumably adjustable, as by selection of suitable taps (not shown).

To explore the relationships governing the magnetomotive force acting on the core, replace the core losses by the dissipation in a fictitious shunt resistor R_s, connected across a fictitious winding having

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N_s turns and subject to current $\mathbf{I}_s$ and voltage $\mathbf{E}_s$ as shown. (This simulates the eddy-current loss rather faithfully on an instantaneous basis, but can simulate the hysteresis loss only on an average basis.) If the core is assumed to have infinite magnetic permeability then the total magnetomotive force, considered vectorially, must be zero, or

$$N_a\mathbf{I}_a + N_b\mathbf{I}_b + N_c\mathbf{I}_c + N_s\mathbf{I}_s = 0, \tag{1}$$

where the winding sense associated with positive N, and the reference directions for Φ and the $\mathbf{I}$'s, are such that positive $N\mathbf{I}$ induces positive Φ. If the core is assumed to be lossless then R_s is infinite and $\mathbf{I}_s$ is zero, so that

$$N_a\mathbf{I}_a + N_b\mathbf{I}_b + N_c\mathbf{I}_c = 0. \tag{2}$$

Since the core has infinite permeability it has zero reluctance, and the core flux never leaves the core and therefore links all the windings completely. Flux other than in the core is considered negligible so that leakage inductance is negligible, and the winding resistances are also assumed insignificantly small. Hence the voltage differences $\mathbf{E}$, whose reference polarities are arbitrarily assumed such as to tend to set up currents opposing the $\mathbf{I}$'s, are all at the same phase and are proportional to the respective values of N, thus:

$$\frac{\mathbf{E}_a}{N_a} = \frac{\mathbf{E}_b}{N_b} = \frac{\mathbf{E}_c}{N_c}. \tag{3}$$

The total volt-amperes absorbed in the transformer is $\mathbf{E}_a\mathbf{I}_a + \mathbf{E}_b\mathbf{I}_b + \mathbf{E}_c\mathbf{I}_c$, which equals zero, by Eqs. 2 and 3. The real part of this is zero because the losses are zero, and the quadrature part is zero because the core reluctance is zero.

SIMULTANEOUS EQUATIONS

Figure 2 shows the recommended configuration for the particular case of three equations. In the general case, where the order of the matrix is n, there are required n transformers each having n windings, as well as n sources of voltage $\mathbf{V}$. The latter are adjustable and are all at the same phase (except for possible shifts of 180°, indicating negative values), and can be obtained in any convenient manner as by resistive voltage dividers.

A typical voltage rise across a winding is $\mathbf{E}_{11}$, which in suitable units may be expressed as $jN_{11}\Phi_1$ (where $j = \sqrt{-1}$), the polarity being determined by the separate polarities of N_{11} and Φ_1. It is convenient to sense Φ_1 as the voltage developed across a *search winding* on transformer 1; this may be an independent winding (not shown) or may be any one of the windings actually connected into the circuit. If the turns value of this winding is called N_1, the voltage is $jN_1\Phi_1 \equiv \mathbf{E}_1$, and

$\mathbf{E}_{11} = N_{11}\mathbf{E}_1/N_1 \equiv r_{11}\mathbf{E}_1$, where r_{11} may be called the turns ratio. Applying these ideas to all the other windings, we express the voltage summations as follows:

$$\left.\begin{aligned} r_{11}E_1 + r_{12}E_2 + r_{13}E_3 &= V_1 \\ r_{21}E_1 + r_{22}E_2 + r_{23}E_3 &= V_2 \\ r_{31}E_1 + r_{32}E_2 + r_{33}E_3 &= V_3 \end{aligned}\right\}, \tag{4}$$

where vectorial designations have been omitted because all **E**'s are at the same phase as the **V**'s.

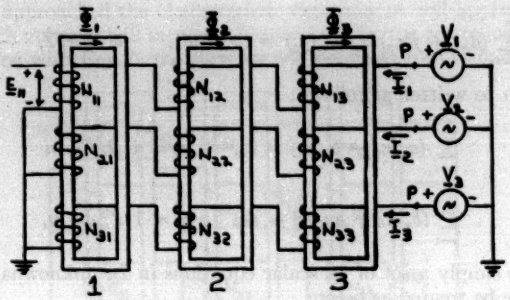

FIG. 2. Simultaneous-equation solver.

To use this device to solve a set of equations such as the following:

$$\sum_{v=1}^{3} A_{uv}X_v = C_u, \qquad u = 1, 2, 3, \tag{5}$$

we set the respective values of V proportional to the values of C, and set the various values of r proportional to the corresponding values of A; then the values of E are proportional to the respective values of X. A different constant of proportionality may be used for each individual equation, if desired.

The extension to a matrix of order greater than three is obvious.

To determine the vectorial currents **I**, write an equation similar to Eq. 2 for each transformer, thus:

$$\left.\begin{aligned} N_{11}\mathbf{I}_1 + N_{21}\mathbf{I}_2 + N_{31}\mathbf{I}_3 &= 0 \\ N_{12}\mathbf{I}_1 + N_{22}\mathbf{I}_2 + N_{32}\mathbf{I}_3 &= 0 \\ N_{13}\mathbf{I}_1 + N_{23}\mathbf{I}_2 + N_{33}\mathbf{I}_3 &= 0 \end{aligned}\right\}, \tag{6}$$

which shows that the currents are zero, except when the characteristic determinant of these equations is zero. When the latter is true, the characteristic determinants of Eqs. 4 and 5 are readily shown to be zero

also, and the values of X are indeterminate. In practice the currents become appreciable, and the X's difficult to determine with accuracy, when the characteristic determinants become small compared with the average magnitude of their individual terms, in which case the equations are said to be ill-conditioned.

Next suppose that the simultaneous equations are complex, thus:

$$\sum_{v=1}^{n} \mathbf{A}_{uv}\mathbf{X}_v = \mathbf{C}_u, \qquad u = 1, 2, \cdots n,$$

which may be expressed as

$$\sum_{v=1}^{n} (a_{uv} + jb_{uv})(x_v + jy_v) = c_u + jd_u, \qquad u = 1, 2, \cdots n.$$

This can be written as follows:

$$\sum_{v=1}^{n} (a_{uv}x_v - b_{uv}y_v) = c_u, \qquad u = 1, 2, \cdots n$$

$$\sum_{v=1}^{n} (b_{uv}x_v + a_{uv}y_v) = d_u, \qquad u = 1, 2, \cdots n,$$

which is simply a set of $2n$ scalar equations in $2n$ unknowns, and can therefore be treated as before.

SECULAR EQUATIONS

The following equations are of a type which commonly appear in vibrational and other problems, as discussed by Soroka (1, p. 120):[3]

$$(A_{11} - \lambda^2)X_1 + A_{12}X_2 + A_{13}X_3 = 0$$
$$A_{21}X_1 + (A_{22} - \lambda^2)X_2 + A_{23}X_3 = 0$$
$$A_{31}X_1 + A_{32}X_2 + (A_{33} - \lambda^2)X_3 = 0.$$

It is desired to find the positive values of λ, namely the *eigenvalues*, which will permit the X's to take on values regardless of the fact that the right-hand side of each equation is zero. This can happen only if the characteristic determinant of the equations is zero. As shown in Ref. 1, the number of eigenvalues is in general equal to the order of the matrix. In a vibrating system, for example, each eigenvalue might represent a natural frequency of sinusoidal oscillation, and the values of X corresponding to each eigenvalue would then represent relative amplitudes at different points of the system. Absolute amplitudes cannot be obtained from the above equations alone.

This type of problem can be solved by the device of Fig. 3, which is

[3] The boldface numbers in parentheses refer to the references appended to this paper.

the same as Fig. 2 except for the following modifications: (1) a winding of turns value N' (with suitable subscript) is added on each transformer, and (2) the voltage sources are replaced by a single source of very small voltage ΔV. The values of N' are negative and are adjustable so that the associated turns ratios, such as $N_1'/N_1 \equiv r_1'$, can be made to simulate various values of $-\lambda^2$, using the appropriate proportionality constant for each individual equation.

Now vary all values of N' together, and in the same small increments, so as to simulate values of λ varying from zero upward. For values of λ other than the eigenvalues, the search voltages $E_1, E_2, \cdots$ will be very small because ΔV is very small. However, as each eigenvalue is approached the characteristic determinant will approach zero, the search voltages will increase sharply, and, by the reasoning given in connection with Eqs. 6, the currents will rise from zero to finite values.

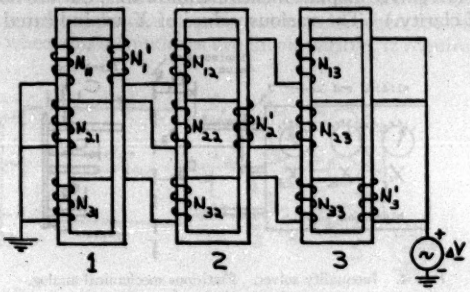

FIG. 3. Eigenvalue solver.

In the practical case the eigenvalues can be detected as those which maximize either the average or rms. value of the magnitudes of the search voltages. The values of X associated with each eigenvalue are proportional to $E_1, E_2, \cdots$ as before.

SIMULTANEOUS INEQUALITIES

The following type of expression appears in connection with the theory of linear programming (2, Ch. 14), of interest in problems concerning optimum decisions in economics, military strategy, and other fields involving many inter-related factors:

$$\sum_{v=1}^{n} A_{uv} X_v \geqq C_u, \qquad u = 1, 2, \cdots m. \tag{7}$$

Note that m may be greater than n, and that the "greater than" sign can be changed to a "less than" sign by multiplying both sides of the expression by -1.

Typically it is desired to know whether there exists a set of values for the X's, which are n in number, which satisfy the m inequalities, in which case the latter are said to be *compatible*. Another part of the problem might be to evaluate this set subject to the restriction that a selected one of the left-hand expressions be a maximum, possibly with the further restriction that no X be negative.

Problems of this type can be solved by a suitable modification of the device of Fig. 2. To aid in the understanding of this modification we shall first discuss it in the form of a fictitious mechanical analog suggested to the writer by Dr. John Kreitner.[3]

Imagine that the inter-connected transformers in Fig. 2 are replaced by a "black box" in which the outputs, measured at points corresponding to P in Fig. 2, are the displacements of sliding rods instead of voltages, each displacement being indicated as D (with suitable subscript) in Fig. 4. (Negative displacements are allowable, but are not shown for the sake of clarity.) The various values of X are indicated by dials or

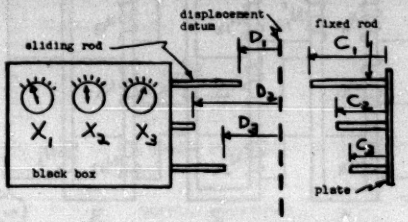

FIG. 4. Inequality solver. Fictitious mechanical analog.

other suitable means. While only three sliding rods and X's are shown, there are actually m of the former and n of the latter. A *plate*, which can move only horizontally, is fitted with fixed rods of length corresponding to the respective C's, each fixed rod being in line with the corresponding sliding rod emerging from the black box.

As an introduction to this device, we shall first solve expressions (7) considered as equalities, with m equal to n. To do this merely bring the plate up to the displacement datum, and, holding the sliding rods in contact with the fixed rods, read the various values of X.

Next we shall consider expressions (7) as they actually are, and shall determine whether they are compatible. If the plate can be brought as far leftward as the displacement datum without being stopped by contact forces between the sliding and fixed rods, the expressions are compatible, since no D is less than the corresponding C. (The rods and associated mechanism are assumed to have zero friction and backlash and infinite modulus of elasticity.) Further, if the plate is kept in this

[3] President, American Hydromath Corporation.

position and one of the sliding rods is pushed to the left as far as possible, there is obtained a set of X's subject to the restriction that one of the left-hand sides in the expressions is maximized. If the further restriction is imposed that no X be negative, then suitable stops, depending on the internal design of the black box, must be used to prevent the X's from falling below zero.

Note that whether the expressions are compatible or not, the plate cannot be stopped in its leftward motion until as many rods are in contact as there are X's. This follows from the fact that in the case of m simultaneous equations in n unknowns the X's are not defined if $m < n$.

By energy considerations it can be shown that compressive *force* in Fig. 4 is analogous to current magnitude in Fig. 2. Hence by previous reasoning the rod force is in general zero whenever the number of sliding rods in contact with fixed rods equals (or is less than) the number of X's. When the plate is brought to a stop by contacts between the sliding and fixed rods, as when the inequalities are incompatible, it requires infinite

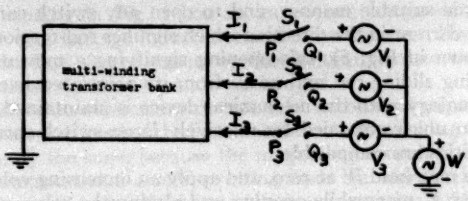

FIG. 5. Inequality solver. Actual electrical computer.

force to produce further leftward motion. If tensile force is applied to a sliding rod for any reason, it is analogous to current flowing in the direction opposite to that shown in Fig. 2.

Figure 5 shows the electrical circuit actually used to perform the computation. It is similar to Fig. 2 except that the number of transformers is n, the number of windings per transformer is m (although only three are implied in the sketch), switches S are inserted at the transformer outputs, and the voltage sources are returned to an additional source of voltage W instead of to ground. For any particular problem the V's are fixed, as before, but W is variable. Both V and W, as well as the currents I, are shown as scalars for simplicity.

W corresponds to the displacement of the plate of Fig. 4 to the *left* of the displacement datum, and the V's to the length of the respective fixed rods. Hence the voltages at points Q correspond to the distances of the fixed-rod ends to the left of the displacement datum. Similarly, the voltages at points P correspond to the distances D.

To test the inequalities for compatibility open all switches, choose

the V which is largest in algebraic value (say V_1), and set W equal to the negative of this value, so that the voltage at Q_1 is zero. (It is assumed that the largest V is positive, else compatibility is assured.) Close switch S_1; this is analogous to bringing the first sliding rod in Fig. 4 into contact with its fixed rod, whose end is at the displacement datum. No change in the transformer voltages is involved, since the voltage at all P's was zero before the switch was closed. The switch-voltages, or voltage rises measured across the *open* switches in the direction from Q to P, are positive, since the points Q other than Q_1 are below it in voltage.

Now increase W continuously (corresponding to a movement of the plate to the left), and observe the switch-voltages. As these become less and less and some finally reach zero, close the corresponding switches, until $n + 1$ switches are closed. For further increase of W the currents through the closed switches may rise suddenly from zero to infinite values (in practice this is indicated by a sharp change from very small to relatively large values), as discussed for the forces in the mechanical analog. Hence it is necessary to monitor the switch currents in some suitable manner, and to open any switch carrying relatively large current in the direction which signifies rod-tension (opposite to that shown in Fig. 5), this opening signifying a movement of the corresponding sliding-rod end away from its associated fixed-rod end. Thus the analogy with the mechanical device is maintained, and, if W reaches zero unaccompanied by relatively large switch-currents, then the inequalities are compatible.

Next we may hold W at zero, and apply an increasing voltage to one of the points P, meanwhile opening and closing the other switches according to the criteria just described. When the voltage in question increases to the point where the switch-currents suddenly become large, the transformer search voltages yield the unknowns associated with the maximization of a selected left-hand side in expressions (7).

If the further restriction is imposed that no X be negative, it is necessary to monitor the transformer search voltages, and to short the windings of any transformer in which the search voltage tends to be negative. A practical modification of this procedure is to short only the search winding itself; by Eqs. 3 this will (ideally) keep all windings on the transformer at zero voltage, and will also furnish an indication, by the direction of the circulating current within the shorted winding, as to whether the search voltage is tending to go positive, in which case the winding would be re-opened.

ERRORS AND THEIR REDUCTION

Only those errors caused as a result of transformer imperfections will be discussed, since these are considered to be the primary limitation on the over-all accuracy of the computer.

Since the magnetic permeability of the core material is not actually infinite, the right side of Eq. 1 is not zero, but is proportional to the product of vectorial flux and the reluctance of the core. Also, R_c in Fig. 1 is not infinite, so that $\mathbf{I}_c$ actually exists. The phase of the latter is opposite to that of $\mathbf{E}_c$, and therefore lags the phase of Φ by 90°. Thus Eq. 1 may be re-written as follows:

$$N_a\mathbf{I}_a + N_b\mathbf{I}_b + N_c\mathbf{I}_c = \Phi(F + jG), \tag{8}$$

where F and G are positive scalars which depend on the core reluctance and losses respectively, and the right-hand term above is presumably small compared to the average magnitude of the left-hand terms. As noted before, hysteresis losses are represented (within G) on an average but not on an instantaneous basis, thus introducing harmonics of voltage and current into the system. A further source of harmonics is the fact that the magnetic permeability varies during each cycle, so that the reluctance can be defined by F only on an average rather than on an instantaneous basis.

Each winding in Fig. 1 has an impedance composed of reactance associated with leakage inductance and of resistance. However, if the voltages in Eqs. 3 are taken as flux-induced rather than terminal voltages, these equations remain unchanged.

The above considerations do not take account of capacitive effects in the transformer, and of the fact that the core flux linking each winding is not exactly the same because the magnetic permeability is finite.

The computational errors resulting from transformer imperfections will be discussed only for the simultaneous-equation solver of Fig. 2. By Eq. 8 the right-hand sides of Eqs. 6 are now relatively small quantities rather than zero, so that small currents exist. Let us assume for convenience that the transformer search windings are other than those actually connected in the circuit, and are therefore free of current. (Of course no appreciable current should be drawn in measuring search voltage.) Then Eqs. 4 become:

$$\left.\begin{aligned} r_{11}\mathbf{E}_1 + r_{12}\mathbf{E}_2 + r_{13}\mathbf{E}_3 &= \mathbf{V}_1 - \mathbf{I}_1\textstyle\sum_1\mathbf{Z} \\ r_{21}\mathbf{E}_1 + r_{22}\mathbf{E}_2 + r_{23}\mathbf{E}_3 &= \mathbf{V}_2 - \mathbf{I}_2\textstyle\sum_2\mathbf{Z} \\ r_{31}\mathbf{E}_1 + r_{32}\mathbf{E}_2 + r_{33}\mathbf{E}_3 &= \mathbf{V}_3 - \mathbf{I}_3\textstyle\sum_3\mathbf{Z} \end{aligned}\right\}, \tag{9}$$

where $\sum_1\mathbf{Z}$, for example, is the summation of coil impedances in series with $\mathbf{V}_1$. Vectorial designations have been retained, because the $\mathbf{E}$'s are now not in phase with the $\mathbf{V}$'s.

The error terms, namely the extreme right-hand terms in the above equation, can be reduced in two different ways: (1) by compensating for core imperfections, thus reducing the currents (to zero in the ideal case); (2) by compensating for winding impedance, thus reducing the

impedance summations $\sum \mathbf{Z}$. Certain methods of performing these compensations are discussed by Mallock (3). Here we shall describe only one particularly economical method which is adequate if the order of the matrix is not greater than ten or so, and if errors of the order of 1 per cent are tolerable.

The reluctance of each core can be compensated, at a given frequency, by shunting a capacitance across any winding on the transformer. To understand this, evaluate $\mathbf{I}_a$ in Eq. 1 in terms of Φ and N_a, with a capacitance shunted across R_a in Fig. 1. By suitable choice of this capacitance Eq. 8 becomes:

$$N_a\mathbf{I}_a + N_b\mathbf{I}_b + N_c\mathbf{I}_c = jG\Phi,$$

where the right-hand term is typical of those which must now be entered on the right sides of Eqs. 6. These terms are in phase with the transformer search voltages, so that the currents are also in phase with these voltages. Now place a capacitor, of the same reactance (at the operating frequency) as the inductive part of $\sum \mathbf{Z}$, in series with each $\mathbf{V}$ in Fig. 2. Then Eqs. 9 become:

$$\begin{aligned} r_{11}E_1 + r_{12}E_2 + r_{13}E_3 &= V_1 - I_1\textstyle\sum_1 R \\ r_{21}E_1 + r_{22}E_2 + r_{23}E_3 &= V_2 - I_2\textstyle\sum_2 R \\ r_{31}E_1 + r_{32}E_2 + r_{33}E_3 &= V_3 - I_3\textstyle\sum_3 R, \end{aligned}$$

where $\sum R$ is the summation of winding resistance, and vectorial designations are omitted because all terms are at the same phase. It is now merely necessary to measure each I and compensate V accordingly; one way of doing this is to note the voltage across an additional series resistor of value $\sum R$, and then to increase V by twice this voltage, considered algebraically.

A limitation of this method is that the harmonics due to variations in magnetic permeability, and to the instantaneous difference between hysteresis and resistor losses, remain in the system. Further, the desired value of each shunt capacitance is not constant, but depends to some extent on the core flux, which is not known in advance. On the other hand the desired values of series capacitance are known in advance, but vary with each choice of N's, as do the values of $\sum R$. Since the leakage flux paths are largely in air, the leakage inductances (and, therefore the series capacitances) are relatively independent of current magnitude, and introduce no appreciable harmonics.

To reduce the errors resulting from harmonics and from phase shifts due to imperfect compensation of inductances, it is advisable to measure each desired voltage by nulling it, through a sensitive a-c. meter, against the wiper voltage of a potentiometer which is supplied from the same basic voltage supply as the V's, the position of the wiper then serving

as an indication of relative voltage. The harmonics and phase shifts prevent a true null from being obtained, but hardly affect the wiper position corresponding to a minimum reading, which is observed instead of the null. Negative voltages are measured by reversing the polarity of the potentiometer supply.

Variation of Error with Order of Matrix

In the uncompensated case the values of $\sum \mathbf{Z}$ in Eqs. 9 can be expected to increase linearly with n, the order of the matrix. By applying the right side of Eq. 8 to Eqs. 6, the values of $\mathbf{I}$ in Eqs. 9 may be thought to be independent of n, since each term in Eqs. 6 is in general of the same order as the right-hand side irrespective of n; however, since the length of the magnetic path in each transformer is presumably proportional to n since n windings must be accommodated, the values of F and G, and consequently of $\mathbf{I}$, may be expected to increase proportionally with n. Hence the uncompensated error in Eqs. 9 is of the order of n^2. Also, since the compensation cannot be perfect, the lower limit of error which is realizable in *any* type of compensated system may be expected to be roughly proportional to n^2.

COMPARISON WITH PREVIOUS COMPUTERS

The present device is closely related to a device described by Mallock (3). The chief differences are:

1. In the prior device the V's are introduced by a separate multi-winding transformer supplied by a single voltage. Thus the V's are subject to error introduced by this transformer, whereas in the present case each V is separately adjustable to its measured value.

2. The present device has pictorial similarity with the equations which it is designed to solve, as can be seen by inspection of Fig. 2 and Eqs. 4. This is of particular advantage when the operating procedure is complicated, as in the case of the secular equations and simultaneous inequalities described above. In the prior device the pictorial similarity is less direct.

An outstanding advantage of both the present device and Mallock's is that no iteration, either manual or automatic, is required. This is in contrast with most practical simultaneous-equation solvers (1, Ch. 3). Further these devices use no amplifiers, except possibly in the compensation of secondary effects.

EXPERIMENTAL WORK

The practical aspects of the device will be illustrated by discussing an experimental solution actually performed for the following problem:

Check that the following inequalities, in which no restriction is placed on the polarities of the unknowns, are compatible:

row ↓ \ column →	1	2	3	4	5	6		C
1	100	1	0	−3	0	−60.3		500
2	−100	0	−9	−9	−27	0		−500
3	−1	−100	0	0	60	0		−500
4	−59.2	100	0	−27	0	3		500
5	0	9	100	−59.6	0	0	=	500
6	0	3	59.7	100	0	0		100
7	−9.3	0	−100	0	−9	27.2		−500
8	26.8	0	−27	100	0	0		−200
9	0	−60	0	0	100	9.1		−200
10	0	−27	0	0	100	−100		300

where the quantities on the left are coefficients of the unknowns X, and the quantities on the right are the respective right-hand constants C.

The coefficients were chosen to fit the numbers of turns on the windings of certain multi-winding transformers which were available to the writer. The transformer cores were of high-permeability nickel-iron, with a lamination thickness of 0.005 in. and a cross-sectional area of about $\frac{1}{4}$ sq. in. The windings were of 24-gage copper, and the ratio of the number of turns of each winding to its associated coefficient in the table was five. A 500-turn winding on each transformer was used as the search winding, and a $\frac{1}{2}$-microfarad capacitance was shunted across this winding to compensate for core reluctance. No other compensation was used in the system.

The voltages at points Q in Fig. 5 were calculated for different values of W, and were obtained by resistive voltage-dividers using a 60-cps. 6-volt source. Voltages were measured by the null method described above, using a ten-revolution potentiometer equipped with a suitable pointer and scale to indicate the angular position of the wiper. The null meter was an ordinary 500-microampere a-c. instrument, and was in series with a comparatively high resistance, for safety, except when a pushbutton was depressed. Currents were measured in terms of the voltage across 100-ohm resistors inserted at the right of each point Q, the voltage at Q being held to its correct (but uncompensated) value in spite of the resistor voltage drop.

In the course of solving the problem according to the techniques described in connection with Figs. 4 and 5, it was necessary to connect the circuit so as to solve six different sets of simultaneous equations. For these sets the currents averaged about one or two mils, with a maximum of about five mils, and were almost always in the direction corresponding to compression of the rods in Fig. 4. The final solution, with rows 1, 2, 3, 4, 5 and 7 connected, was as follows:

X_1	X_2	X_3	X_4	X_5	X_6
3.81	7.08	3.85	−0.89	3.53	−1.82

With these values it can be checked that the error of each individual equation in the final circuit (obtained by computing the left-hand value for the above values of X, subtracting the associated C, and dividing the difference by the average of the C's corresponding to the connected V's) is about 0.25 per cent, which was typical for all the six different sets of equations. Further, the excess of the left-hand values over the respective C's is, for rows 6, 8, 9 and 10, respectively, as follows: 62, 109, 111 and 44. This checks the compatibility.

REFERENCES

(1) W. W. SOROKA, "Analog Methods in Computation and Simulation," New York, McGraw-Hill Book Co., 1954.

(2) J. C. C. MCKINSEY, "Introduction to the Theory of Games," New York, McGraw-Hill Book Co., 1952.

(3) R. R. M. MALLOCK, "An Electrical Calculating Machine," *Proc. Royal Soc.* (*London*), Series A, Vol. 140, pp. 457–483 (1933).

Metals Testing Chambers Operated at 452 Degrees Below Zero.—Metallurgists at the Research Laboratories of Westinghouse Electric Corporation are conducting tensile tests on metals at temperatures as low as − 452 F. The metal specimens are stressed within a specially designed chamber which has been cooled with liquid helium. Results of these tests will provide engineers with needed information regarding types of metals that are best suited for use under extreme temperature ranges. Information of this sort may well be useful in the design and development of guided missiles and future supersonic aircraft.

"It is not at all impossible," E. T. Wessel, research engineer for Westinghouse, explained, "that aircraft of the future will use fuels that are stored as liquefied gases in metal containers at extremely low temperatures. Preliminary studies of the properties of metals at low temperatures will be essential to developments of this kind."

Oxygen for human consumption during high altitude aircraft operation already is being stored in liquid form in metal containers at temperatures of about − 300 F. This arrangement is more practical than using compressed gas since an equivalent size storage space contains a much larger supply of oxygen in liquid form.

Although much larger testing apparatus has been used in low temperature experiments in the past, the Westinghouse-developed chamber, which is only slightly larger than a hand fire extinguisher, is believed to be the first of its kind to use liquid helium in order to attain the − 452 F. mark for purposes of tension testing. Prior to use of liquid helium as refrigerant, tests were conducted at temperatures as low as − 320 F. using liquid nitrogen.

A sample of the metal to be tested, about one inch long, and ¼ of an inch in diameter, is placed inside the special vacuum insulated chamber. The sample is held securely at each end in special chucks made of Discaloy, an alloy developed several years ago by Westinghouse to withstand high temperatures and high stresses for extended periods of time. Liquid nitrogen is used for initial cooling of the chamber from room temperature to − 320 F. At this point liquid helium is introduced to take the temperature down to − 452.

Nitrogen is used in the room temperature to − 320 F. range because it is considerably more economical and efficient than is the use of helium at these temperatures. Using these two refrigerants, tests can be conducted at any temperature from zero to − 452 F.

When chamber and test sample are stabilized at the desired temperature, a tension load is applied to the sample and is gradually increased until the piece of metal breaks. During the test the temperature of the metal specimen and also the stress-strain readings from the sample are recorded electrically on graphic charts. In current experiments, the maximum stress that can be applied to the ¼-inch diameter sample is 260,000 pounds per square inch.

In addition to providing basic engineering data necessary to the development of such things as low temperature liquid fuel and coolant storage tanks for guided missiles, Mr. Wessel said the studies will improve our understanding of why metals behave as they do under various conditions. The fact that low temperature liquids are being considered for coolants in guided missiles was disclosed in September, 1954, in Boulder, Colorado, at the dedication of the new National Bureau of Standards Laboratories there.

NUCLEAR ENERGY NEWS

ARMOUR NUCLEAR RESEARCH REACTOR

Another nuclear reactor has been designed for private industrial research. It will be built for the Armour Research Foundation by North American Aviation, Inc., Downey, California.

It is proposed to locate the new reactor at Armour's operations on the Chicago campus of the Illinois Institute of Technology, of which the Armour Foundation is a part. The reactor and associated equipment, expected to cost about $500,000, are scheduled to be completed by the end of 1955.

The reactor will be housed in a room about 48 ft. long, 72 ft. wide, and 30 ft. high, located in a new building containing a group of research rooms. The reactor core will be a steel sphere about one foot in diameter containing about four gallons of a water solution of uranyl sulphate, enriched in Uranium 235.

The reactor core will be surrounded by an 8 × 5 × 5-ft. stack of graphite bars which act as a reflector. The graphite stack is completely enclosed in a steel tank, except for those areas opened to permit access to the neutron supply from the core. Five-foot thick dense concrete blocks form the exterior shield for the reactor, giving an over-all dimension of 18 ft. long, 16 ft. wide, and 11 ft. high for the shielded reactor structure.

Rate of fission of uranium in the reactor will be controlled by four boron rods. These rods, when placed near the reactor core, absorb neutrons, thus stopping the fission process. When the rods are withdrawn fission begins again. With this control it is possible to operate the reactor at various power levels by regulating the rate of fission. The maximum level will be 50,000 watts.

A particular feature of this reactor is its "self-contained" design which confines all the radioactivity within the shield. No fumes, gases, smoke, or any other materials will be exhausted or discharged from the reactor. This design, together with the inherent safety features of the solution-type reactor, make it particularly suitable for the Armour Research program.

Fissionable material to "fuel" the reactor will be obtained from the Atomic Energy Commission on an "extended loan" basis. Armour officials have pointed out that sponsored research with the reactor will be subject to no competition from military applications and to no secrecy of any kind other than that called for in the protection of the individual sponsor's programs.

The reactor will be available to industrial and government sponsors for a wide range of nuclear research, just as will the Battelle research reactor, also announced recently.* Not only will the reactor provide a copious source of neutrons, but also it will make available gamma rays of considerable intensity that will facilitate studies of radiation effects in chemical and biological systems.

Several areas of study now appear likely, according to Dr. Richard F. Humphreys, in charge of Armour's nuclear reactor project: (1) sterilization and pasteurization of foods and drugs; (2) the structure of plastics, rubber, and similar materials; (3) the mechanism of catalysis and radiation effects on catalytic agents; (4) transistors and semiconductors; (5) the structure of glass and ceramics, which when understood could lead to the development of materials with improved properties; (6) the nature of friction, which could lead to new lubrication developments; (7) peripheral studies in power reactors; (8) structural studies in organic and inorganic chemistry; (9) trace element determinations; and (10) new medical applications—since literally hundreds of diagnostic and therapeutic techniques depend upon radioisotopes.

NEW DIRECTOR OF AEC REACTOR DEVELOPMENT

Mr. W. Kenneth Davis was appointed Director of Reactor Development of the Atomic Energy Commission of February 25, 1955, to succeed Dr. Lawrence R. Hafstad. Mr. Davis had been Deputy Director of the Division since August, 1954, and Acting Director since the departure of Dr. Hafstad, January 1, 1955. He was first appointed to the AEC staff in April, 1954, as assistant director in charge of technical projects of the division.

Mr. Davis was born in Seattle, Washington, July 26, 1918. He attended the University of California, majoring in chemistry and in 1940 was granted a Bachelor of Science degree in chemical engineering by Massachusetts Institute of Technology. He obtained a Master of Science degree in chemical engineering at M.I.T. in 1942. He was professor of engineering at the University of California before joining the AEC staff.

NEW AEC REACTOR SCHOOL

The School of Nuclear Science and Engineering is under way at the Argonne National Laboratory near Chicago, which is operated for the Atomic Energy Commission by The University of Chicago. It is one of the major projects undertaken by the AEC in cooperation with the State Department and the Foreign Operations Administration in support of the President's Atoms-For-Peace program.

There are 31 scientists and engineers from 19 foreign nations among the initial enrollees. There also will be nine U. S. students in the class

* See this JOURNAL, p. 349, April 1955.

of 40. The nations represented in the first class are: Argentina, Australia, Belgium, Brazil, Egypt, France, Greece, Indonesia, Israel, Japan, Mexico, Pakistan, The Philippines, Portugal, Spain, Sweden, Switzerland, Guatemala, and Thailand.

The seven-month session will include unclassified courses in design, construction, and operation of reactors for nuclear research; principles of design of nuclear power reactors; handling of irradiated materials and other related peacetime applications of nuclear energy. Outstanding specialists from other AEC Laboratories will be scheduled for special lectures.

LIQUID METAL FUEL REACTOR

An engineering evaluation of a nuclear power plant system using liquid metal as fuel is under way at the Atomic Energy Commission's Brookhaven National Laboratory. The feasibility study is being done by a group of 14 industrial and three other organizations.

The Babcock and Wilcox Company, New York, has organized and is in charge of the study. Seventeen scientists and engineers, working full time, and several more part-time consultants are engaged in the work. They are to submit a final report June 30, 1955.

Preliminary designs for the system, known as Liquid Metal Fuel Reactor (LMFR), were developed by Brookhaven. The system is intended to generate electric power, "breed" new fuel for itself, and deliver by-products to waste tanks—all in continuous processes. It would provide the first usage of a liquid metal alloy, in this case uranium-bismuth, as the fuel stream to inter-connect continuous processes.

In the LMFR, fission of uranium 233 atoms would occur in the core, which is a perforated graphite cylinder 5 ft. in diameter. Considerable heat would be given off, and would be promptly conveyed by the molten uranium-bismuth alloy out of the core. As in other schemes for utilizing nuclear power, another liquid metal would deliver the heat to water, producing steam to spin a turbine which would drive a generator of electricity.

When a heavy atom like U 233 fissions, each fragment, approximately half of the uranium atom, is a newly created element of intermediate weight. Some of these new products of fission appear as gases. Therefore, in one LMFR process, part of the molten uranium-bismuth would be piped off for removal of such gases as xenon and iodine, by "sweeping" them out of the liquid metal with an inert gas such as helium. In another process, liquid salts such as potassium and lithium chloride could draw off fission products while leaving the uranium in the bismuth. Uranium-bearing bismuth would be pumped back through the core to continue the production of heat.

Surrounding the core would be a graphite structure through which flows a mixture of thorium and bismuth. This arrangement is called a "blanket." The excess neutrons from the fissioning U 233 atoms in

the core would be captured by the thorium in the surrounding blanket and form more U 233. LMFR is therefore a "breeder" which would replace the fuel as it is consumed. The new U 233 produced in the blanket would be continuously removed by extraction with molten salt. This new U 233 would go to a storage tank. From there, it would be fed back through the core when needed, and the excess U 233 would be available for shipment to other reactors.

Since not all of the fundamental information pertaining to the LMFR as it may be built is known at present, the over-all evaluation will necessarily be based on certain assumptions in chemistry, physics and engineering. An appraisal of the nature and scale of these assumptions and an estimate of their probable effect on the validity of the conclusions drawn will be made.

STUDY OF REACTOR TRANSIENTS

A new series of tests on reactor transients is to be conducted by the Philips Petroleum Co., which operates the National Reactor Testing Station for the AEC at Idaho Falls, Idaho. Contracts have been let for construction of four buildings to house mechanical and electrical equipment, an instrument cell, a test pit, and controls. They are to be ready for use this summer.

The test work will be similar to experiments which have been performed at the NRTS by Argonne National Laboratory since the summer of 1953. Those tests consisted of setting up and operating a water-cooled and moderated reactor and imposing conditions normally expected to cause a "run away." (See pp. 22 and 23, Sixteenth and Seventeenth Semiannual Reports of the Atomic Energy Commission.)

The Argonne experiments continued until last July 22, when a final short-period excursion was performed, in which the power was allowed to rise to more than a million kilowatts in a tenth of a second. This excursion—more severe than could be reasonably expected to occur in a reactor accident—resulted in destruction of the reactor core and some associated equipment. Another reactor, similar but pressurized, has since been set up and operated by Argonne at the NRTS.

The new facility to be constructed is intended to study the transient conditions of a reactor—what happens when a reactor suddenly passes from a stable to an unstable operation and back again—in greater detail than the previous experiments. There will be additional instrumentation, for example.

As in the case of the Argonne experiments, precautions will be taken to protect the operating personnel, as well as to prevent the release of any radioactivity in such a manner as to present a health hazzard. (Past experiments have demonstrated the feasibility of confining radioactivity that might be released in the course of such tests within a small area immediately surrounding the test site.) The control building will

be located approximately one-half mile from the test pit containing the reactor core.

PIPING INVESTIGATION SPONSORED BY ASME AND AEC

The Atomic Energy Commission and the American Society of Mechanical Engineers will share the cost of a $25,000 engineering project to develop information in the field of high temperature piping. The investigations will be performed by the AEC's Knolls Atomic Power Laboratory, Schenectady, New York, which is operated by the General Electric Company. The ASME, on behalf of American industry, will contribute $10,000, and a group of ASME technical experts will be available at no cost to the government for consultations in the programming and evaluation of the work.

The project will continue studies of thermal fatigue in ductile metals which were originally undertaken by the AEC to provide information for the reactor development program. General engineering information applicable to heat transfer systems will be developed which will be of future benefit to the AEC program.

Private industry has an immediate need for this type of information, and the Society has undertaken to sponsor the work for this reason. The testing facilities to be used and the resulting information are unclassified.

PORTABLE THULIUM X-RAY UNIT

The Atomic Energy Commission has announced plans to assist private industry in the commercial development of portable thulium X-ray units.

Development of a small, relatively inexpensive and portable device by the Argonne National Laboratory of the University of Chicago, was announced last spring. (*Nucleonics* for May 1954 contained three articles about it.) The unit contains about 200 milligrams of radioactive thulium metal or oxide, pressed into an aluminum capsule. The capsule is recessed into a small cylinder which rotates within an outer shield of lead. The entire unit is approximately six inches in diameter and seven inches long and weighs about 20 pounds. The activity level is about 250 millicuries.

The AEC will not engage in the commercial production of the thulium or in the manufacture of the units. It is expected that private industry will be able to supply the potential market. Technical information and limited consultation will be provided to firms interested in the commercial development of the units.

As further aid the AEC has made arrangements with the Argonne Laboratory to fabricate fifteen encapsulated sources and ten complete thulium X-ray units. They will be available on loan to qualified industrial concerns for developmental studies and to qualified non-profit

academic institutions and Government agencies for research, developmental studies and experimental field applications.

GENEVA CONFERENCE ON ATOMIC ENERGY

The United States Government has accepted an invitation from the United Nations to participate in an International Conference on the Peaceful Uses of Atomic Energy at Geneva, Switzerland, August 8–20, 1955.

Primary responsibility for the technical planning and preparation for the United States participation has been assigned to the United States Atomic Energy Commission. The Commission has named Dr. George L. Weil, former Assistant Director of its Reactor Development Division and now a consultant to the Commission, as Technical Director for United States Participation in the International Conference.

The Conference is an outgrowth of the atoms-for-peace proposals laid before the United Nations on December 8, 1953 by President Eisenhower, when he urged that the atomic resources of the world be mobilized to apply the benefits of atomic energy to the cause of peace. The United Nations has invited 84 nations, including 10 from the Soviet bloc.

The Conference will be devoted to the presentation of information on reactor technology, atomic power, radiation protection, applications of atomic energy to biology, medicine, and agriculture and the industrial uses of radioisotopes.

The Atomic Energy Commission is assembling through key United States educational institutions, industrial establishments and research centers (government and private) technical information in the fields appropriate to the Conference Agenda. It is believed that papers presented by United States scientists and engineers will make substantial contributions to all segments of the Topical Agenda.

The Commission also is planning a technical exhibit at the Conference site at Geneva. More than 60 institutions and firms already have signified interest in participating in this United States Government exhibit.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS

A STUDY OF CELLULAR CONCRETES

During recent years the increasing interest of American industry in the manufacture and use of cellular concretes has led the National Bureau of Standards to study the properties and composition of these light-weight construction materials.[1] The Bureau's program, conducted by R. C. Valore, Jr., of the NBS building technology laboratories, has included both a laboratory study of cellular concretes made with domestic ingredients and a comprehensive survey of literature on European cellular concretes to provide information for American builders.

The low density of cellular concretes is attained by the incorporation of a homogeneous void or cell structure throughout the material. The voids may occupy from 25 to 75 per cent of the total volume of the hardened concrete, and the density of the concrete may range from less than 20 to more than 100 lb. per cu. ft. Most of the European cellular concretes weigh 25 to 50 lb. per cu. ft., however, or about $\frac{1}{6}$ to $\frac{1}{3}$ as much as ordinary concrete.

The production of moist-cured and high-pressure steam-cured precast products of cellular concretes has grown rapidly in Europe in the last 20 years. In Sweden the annual production of precast elements exceeds 1 million cu. yd. Germany, Norway, Russia, Israel and other countries have plants in operation. Most of the structurally important types of cellular concrete products have consisted of precast roof plank, block, beams, and other elements and have been cured in autoclaves in high-pressure steam.

There are a number of methods for producing the cell structure in cellular concrete. These include:

(1) Mechanical methods, whereby air is entrained in the mixture by the high-speed mixing of a cementitious slurry with a "foaming" or "air-entraining" agent, or where a stable, preformed "air-foam" is incorporated or blended into a pre-mixed slurry. Foaming agents may be of the hydrolyzed protein type used for making air-foams to combat gasoline fires, or they may be rosin soaps, certain detergents or other organic agents.

(2) Chemical methods, which depend upon admixtures that react

[1] For further technical details, see "Cellular Concretes," parts 1 and 2, by R. C. Valore, Jr., *J. Am. Concrete Inst.*, Vol. 25, Nos, 5 and 6 (May, June 1954). Also available as a reprint from the American Concrete Institute, 18263 W. McNicholos Road, Detroit 19, Michigan, at a cost of $1.00.

chemically with each other, or with certain compounds already present in the cementitious slurry, to generate uniformly distributed gas bubbles throughout the mix. The most widely used agent in the commercial production of "gas" concretes is aluminum powder, which reacts with alkalies in the cementitious mixture to generate hydrogen.[2] Alternatively, hydrogen peroxide and bleaching powder (calcium hypochlorite) may be used to generate oxygen.

(3) Excess water methods, where a thin slurry is prepared from finely divided cementitious and aggregate materials with several times the amount of water usually required for an equal volume of sand-gravel concrete. Upon curing in high-pressure steam (autoclaving) and then drying, this material acquires a low density by evaporation of excess water and the consequent formation of finely divided voids. Materials made by this process are often called "light-lime" concretes because lime is the usual cementitious ingredient.

The choice of aggregates for cellular concretes usually depends on the type of curing. For curing at ordinary temperatures or in steam at atmospheric pressure, concrete sand or plaster sand may be used; the aggregate may be omitted entirely for materials of the lowest densities.[3] In mixtures cured in these ways the cementitious ingredient is usually portland cement. The Bureau's studies showed that moist-cured mixtures without aggregate usually have been limited to non-structural thermal-insulation applications because the cement content and drying shrinkage are undesirably large at densities high enough to produce structurally adequate material. At a given density moist-cured cement-sand cellular concretes usually had lower strength or higher shrinkage and weight than some lightweight-aggregate concretes.

For a given weight the autoclaved types of cellular concrete have a greater strength; and essentially complete development of strength may be obtained in less than one day. The steam pressure in the autoclave is usually in the range 120 to 160 psi. (350 to 370 F.) and is maintained for six or more hours. The mix for autoclaved cellular concretes includes both a cementitious and siliceous material. The siliceous material or pozzolan should be comparable in fineness with portland cement, or considerably finer than ordinary sand aggregate and may comprise a large proportion of the mix without detrimental effects. The cementitious ingredient may be portland cement, hydrated or unslaked lime, or a blend of cement and lime. During autoclaving, the pozzolan reacts with hydrated lime in the presence of moisture to form calcium silicates that have relatively low drying shrinkage and high strength. The reactions involved are similar to those occurring in the sand-lime brick, also cured in high-pressure steam.

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[2] J. W. Aylsworth and F. L. Dyer, U. S. Patent 1,087,098 (1914).

[3] The term "cellular concretes" does not include concretes made with lightweight aggregates. See paper describing NBS study by R. W. Kluge, M. M. Sparks, and E. C. Tuma, "Lightweight Aggregate Concrete," *J. Am. Concrete Inst.*, Vol. 20, No. 9 (May 1949) p. 625.

Some industrial wastes abundant in this country are high in silica and alumina and include fly ash from coal-burning power plants and from kilns producing expanded lightweight aggregates made from shale, slate, and clay. Some of these materials were used with portland cement in autoclaved cellular concretes prepared at the National Bureau of Standards. Commercial European products are made with lime or portland cement and burnt oil shale, ground silica sand, fly ash or other pozzolans. Both the European commercially-made materials and those prepared at the Bureau had, at a density of 35 to 50 lb. per cu. ft., compressive strengths of 300 to more than 2000 psi., flexural strengths of $\frac{1}{8}$ to $\frac{1}{5}$ of these values, and drying shrinkages of 0.02 to 0.10 per cent, depending upon the nature and proportions of cementitious and pozzolanic ingredients.

Non-autoclaved cellular concretes containing nonaggregate have developed 0.3 to 0.6 per cent linear drying shrinkage and 200 to 400 psi. 28-day compressive strengths at dry densities of 30 to 40 lb. per cu. ft. Cement-sand mixtures (1:4 by weight) weighing 70 to 90 lb. per cu. ft. had 28-day strengths of 250 to 800 psi. and shrinkages of 0.08 to 0.20 per cent. In addition to the advantage of light weight, cellular concretes have relatively high thermal insulation values—10 to 15 times that of commonly used sand-gravel concretes.

A LARGE VIBRATION MACHINE

A vibration machine with a test load capacity of 20,000 lb. has been constructed at the Boulder (Colorado) laboratories of the National Bureau of Standards. The machine was built at the request of the Air Force to study the behavior of heavy apparatus during air and rail shipment. Assembled under the supervision of P. R. Weaver,[1] W. E. Smull,[1] and E. H. Brown of the Bureau staff, the vibration table can produce double amplitudes ranging from 0.020 to 0.065 in. at frequencies up to 60 cycles per second.

Millions of dollars are spent annually to repair or replace apparatus that has been damaged or ruined in normal air or rail shipment. Small, lightweight equipment can usually be packaged in well-padded crates to protect it from damaging shocks and vibrations during transit. However, it is generally much more difficult to protect large, heavy equipment in this fashion. As a result, many larger pieces of apparatus are shipped with no vibration protection at all or with inadequate, built-in shock mounts. The NBS vibration testing facility makes it possible to study the behavior of a wide variety of methods used in packaging, shock-mounting, and protecting heavy shipments.

Several types of electrodynamic systems were considered in designing the vibration machine. It was finally concluded that a mechanical vibration-generator would be most practical and reliable, in view of the large force output required by the Air Force and the moderate frequency

[1] Now with the W. L. Maxson Co.

range. The type of vibration generator chosen uses the inertia reaction of unbalanced counter-rotating shafts to produce simple harmonic motion. The force produced from such a system varies as the square of the driving frequency. The displacement amplitude remains nearly constant.

The machine has two vibration generators, each of which can be given the following unbalance: 50-pound-inches, 180-pound-inches, and 250-pound-inches. The two mechanisms with the same unbalance can be coupled together and driven as a unit, or the mechanisms may be driven separately as required by the test procedure. The mechanisms, which weigh approximately 500 lb. each, are powered by a 10-hp. d-c. motor with a variable speed control.

The vibration generators can be mounted on top of the table for vertical motion, or on the end for horizontal motion. Testing along the third axis is accomplished by rotating the equipment under test 90° in the horizontal plane with the shaker mechanism adjusted for horizontal motion of the table. The table is 12 ft. long and 6 ft. wide, weighs approximately 11,000 lb., and is mounted on four coil springs which give the system a natural frequency of 4 cycles per second. Equipment to be tested can be suspended from the underside of the table.

Several tests were performed, prior to using the machine, to determine the characteristics of the over-all system and the type of motion produced by the table. In one test, a 6800-lb. concrete block was suspended from the table, and two 180-pound-inch mechanisms were coupled together and mounted so as to produce horizontal motion. Three accelerometers were attached to the table to measure both the horizontal and vertical components of the motion. Data taken up to 41 cps. showed that a maximum horizontal acceleration of 4 *g* was reached, and that the unwanted component of vertical acceleration did not exceed 0.17 *g*.

In another test, the concrete block was removed, and the shaker mechanisms were attached so as to produce vertical motion of the table. Accelerometers were oriented along the length of the table so as to measure the variation and magnitude of the vertical acceleration produced. The maximum variation in recorded acceleration along the length of the table was 0.35 *g*. At the highest frequency used in this test—45 cps.—the acceleration reading was 6.5 *g*. (Maximum accelerations of 6 *g* with a 3200-lb. test objective have been recorded.) With two 50-pound-inch mechanisms, the machine has been run to 60 cycles per second. No local resonance of the table or the supporting structures was found within the test frequency range.

This NBS facility is expected to aid materially in the improvement of heavy duty shock mounting, and in the improvement of apparatus design to eliminate failure due to vibration. By proper use of data obtained with the machine, the costly and time consuming problem of repairing or replacing equipment damaged during shipment and service should be minimized.

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

April 20, 1955

The Stated Monthly Meeting of The Franklin Institute was held on April 20, 1955, in the Lecture Hall. S. Wyman Rolph, President, called the meeting to order at 8:15 P.M. Approximately 285 members and guests (of whom approximately 55 were voting members) were present.

The President asked for additions, corrections, or changes to the Minutes of the February Stated Meeting which were printed in the March JOURNAL and to the Minutes of the March Stated Meeting which were printed in the April JOURNAL. There being none, they were, on motion duly made and seconded, approved as submitted.

The Secretary reported that elections to membership, recorded since February 28th, resulted in a net gain of 48 Associate Members and 5 individuals with Library privileges under Company memberships. The total membership as of March 31st was 6,851.

The President stated that the next item of business was one of great importance in the corporate life of The Franklin Institute as it concerned the proposed action by the Members to revise the By-Laws in accordance with the notice of the meeting (a copy of which is filed with the official minutes) to permit the redemption of the outstanding shares of stock of The Franklin Institute, subject to favorable action on the proposed amendment by the stockholders at a meeting to be called for such purpose. The President explained that the stock in question had been sold in varying amounts in the 1860's and the 1880's, of which only 1,031 shares of First Class Stock and 2 shares of Second Class Stock were outstanding. The Board had recommended the proposed action because the stock was not corporate stock in the usual sense of the word and having the stock outstanding created problems for The Institute in connection with research for the Government and in other fields. The President then called upon John Russell, Jr., Esq., Chairman of the By-Laws' Revision Committee to explain the matter in more detail.

Mr. Russell supplemented the remarks of the President and recommended that the proposed action be taken. Mr. Russell stated that on approval of the proposed amendment, a meeting of the stockholders would be called pursuant to Article X of the By-Laws to take action for or against the proposed amendment, and if the approval of the By-Law amendment is given by the stockholders, the Board of Managers would then be in a position to retire the stock in its discretion.

On motion duly made and seconded the following resolution was unanimously adopted by all the members present at the meeting:

RESOLVED, That subject to favorable action of the stockholders of The Franklin Institute at a meeting duly called for such purpose, the By-Laws of The Franklin Institute be amended by adding the following as Section 9 to Article I:

"All shares of the First and Second Class Stock may at any time be redeemed by resolution adopted by a vote of the majority of the Board of Managers taken at any regular or special meeting. Any such resolution shall specify the effective date of redemption which shall be any date within five days of the adoption of such resolution, and shall provide that the holder of any such shares who surrenders the certificate for the same to the Institute within one year from the effective date of redemption shall be entitled to receive, if demanded, the sum of $10 for each share of stock represented by the certificate so surrendered.

"Immediately upon the effective date of any such redemption, all rights of the holders of First and Second Class stock shall cease and determine except the right, upon surrender of certificates of stock within the time limit above provided, to receive, if demanded, the sum of $10 for each share of stock represented by the certificate so surrendered.

"Within five days of the date of any such resolution of the Board of Managers, the Secretary shall (1) send written notice by first class United States mail to all known holders of stock, (such notices to be addressed to the last known address of each such stockholder as the same appears on the records of the Institute) advising them of such action and (2) shall thereafter cause to be published in one paper of general circulation in the City of Philadelphia once a week for two successive weeks a true copy of the resolution of redemption adopted by the Board of Managers."

The President then introduced the speaker for the evening—Dr. Winston E. Kock, Director of Acoustic Research at the Bell Telephone Laboratories. Dr. Kock, a Fellow of the American Physical Society, the Institute of Radio Engineers, and the Acoustical Society, gave a most interesting illustrated talk on "Speech, Music and Hearing." He outlined the physical concepts underlying the speech process and hearing process and discussed methods of analysis and synthesis of speech and music, narrow band speech transmission, and automatic devices for the recognition of speech sounds. Several demonstrations of synthetically-produced speech sounds and music tones were given, as well as examples of speech and music re-created synthetically from actual speech and music.

After an interesting question period, the meeting adjourned at 9:50 P.M. with a rising vote of thanks to Dr. Kock.

HENRY B. ALLEN
Secretary

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, April 13, 1955.)

HALL OF THE COMMITTEE,
PHILADELPHIA, APRIL 13, 1955.

MR. RALPH H. MCCLARREN in the Chair.

The following report was presented for final action:

No. 3245: Work of Waller and Berriman.

This report recommended the award of an Edward Longstreth Medal, each, to Cecil Waller, of London, England, and Robert W. Berriman, of Harrow, Middlesex, England, "In consideration of their contributions to the development of photographic emulsions especially designed for the study of nuclear particles and events, which have made possible important new advances in this field, including the discovery of new nuclear particles and a better understanding of cosmic rays."

JOHN FRAZER,
Secretary to Committee

MEMBERSHIP

ACTIVE MEMBERS ELECTED BY THE BOARD OF MANAGERS

April 20, 1955

ACTIVE FAMILY

Willard E. Hauth, Jr. — Kenneth K. Keown — Robert E. Sessions

ACTIVE

Frederick Adler
John H. Ashenfelter
Earle N. Barber
Victor M. Bell
Miss Eleanor Este Campion
Bert W. Chiappini
Theodore Clattenburg
B. Hubert Cooper
Clarence R. Haas
L. Minford Humrichouse
Ralph S. Kelley
Robert L. Ketcham
George Landis
Ernest M. Marks
Miss Dorothy E. McGillicuddy
Mrs. Stuart Mudd
Charles H. Ostrowski
Thomas D. Paxson
L. W. Roberts
Donald E. Schrader
William W. Tomlinson
Emanuel G. Tulsky
John Vassos
Paul R. Webb
Harry C. Zug

ACTIVE NON-RESIDENT

Oscar J. Horger — Frank V. Martin

NECROLOGY

John G. Burmist '44
John L. Cox '06
Herman Z. Cutler '43
Albert Einstein '35
D. S. Jacobus '99
Lewis H. Kenny '37
John Joseph McVey '00
August C. Mylander '37
Hudson W. Reed '47
Edward W. Robbins '50

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 460 items have been added this month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A. M. until 5 P. M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; 2 P. M. until 10 P. M. on Wednesdays.

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HARMON, DARELL B., JR.: Drop Sizes from Low Speed Jets.
IYENGAR, K. T. S. R. AND S. K. L. RAO: Large Deflections of Simply Supported Beams.
EPSTEIN, BENJAMIN: A Sequential Two Sample Life Test.
MOON, PARRY AND DOMINA EBERLE SPENCER: On the Specification of Bôcher Equations.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, FOUNDER
WILLIAM G. BATT, ACTING DIRECTOR

KREBS 2 ASCITES CARCINOMA GROWN IN CHICKEN EGG

BY
IRVING GALINSKY

Studies were undertaken to determine whether the Krebs 2 ascites carcinoma would grow in fertile chicken eggs. The Krebs 2 ascites tumor grows very rapidly in the peritoneal cavity of the Swiss strain of white mouse, resulting in the death of the mouse in approximately 11 days. When grown as a solid, subcutaneous tumor its growth is slower but still quite rapid, killing the mouse in three to four weeks.

The chicken egg has been used as a medium for tumor growth since 1912 (1). Since then tumors from a wide variety of animals have been grown successfully in the fertile egg, mainly on the chorio-allantoic membrane (CAM) (2) or in the yolk sac (3). The chick embryo has no defensive mechanism against the growth of heterologous tumors, and supplies blood vessels and connective tissue for the tumor. The successful growth of any tumor in the chicken egg depends upon two main factors: (1) the rate of cell division must be rapid enough to allow a fair-sized tumor to develop within the one to two weeks available for growth, between inoculation and the time the chick hatches; (2) the tumor may not have some specific nutritional requirement found in the original host, but not normally present in the chick embryo.

An attempt was made to grow the ascites tumor in three different regions of the egg.

CHORIO-ALLANTOIC MEMBRANE

Krebs tumor in three physical states was used: (1) a fragment of the solid tumor (approx. 2 mm.) was placed onto the CAM; (2) the solid tumor was macerated through stainless steel screens in a 10 cc. syringe and 0.1 cc. of the resultant macerate placed onto the CAM; (3) free ascites cells were centrifuged from ascitic fluid and 0.1 cc. placed onto the CAM.

For the inoculation onto the CAM, a hole was cut in the shell over the vascular area of an eight-day embryo and the tumor was dropped onto the blood vessels. The opening was then sealed with Scotch tape (2). The eggs were opened on the 18th day of incubation.

The most successful method was No. 3, with No. 2 next and then No. 1. Solid tumors grown on the CAM were small and usually failed

to grow upon the second transplantation to the CAM. This also holds true for the macerated solid tumors although somewhat better growth was obtained in the first generation, and there was more chance of growth occurring in the second generation.

Free Krebs ascites cells from the ascitic fluid of the mouse grew for three or four transplant generations on the CAM.

During the first transplant generation to the CAM, the ascites cells grew in the form of a flat, circular sheath about 2 to 3 cm. in diameter. Subsequent transplantations were made by first macerating the tumor through the stainless steel screens. These transplanted tumors grew mostly in the form of distinct nodules. After the fourth transplant, the size of the tumor had decreased to such an extent that not enough was available to continue transplantation. Microscopic observations of tumor sections showed a decrease in the number of mitotic figures as compared to that found in the original suspension of ascites cells. When ascites tumors on the CAM were macerated and inoculated into mice, they produced typical free ascites cell growth in the peritoneal cavity but no tumor when inoculated subcutaneously. Since fewer active cells were needed to produce "takes" upon intraperitoneal inoculation than upon subcutaneous inoculation, this would support the microscopic observations that fewer mitotic cells are present.

YOLK SAC

The yolk sac technique used was essentially that of Taylor (2). The ascites cells were injected into the yolk sac of an embryonated four-day-incubated egg. The cells were injected upward towards the developing blood system.

Tumor growth was obtained in the first generation but subsequent transfer of the tumor resulted in very little or no growth in the second generation. Better growth was obtained from ascites cells centrifuged and resuspended in saline than from cells in suspension in the ascitic fluid. Tumor growth was obtained when a solid ascites tumor, grown from free ascites cells placed on the CAM, was macerated through steel screens and injected into the yolk sac. The amount of this yolk sac tumor was not great, but it was macerated and inoculated, both intraperitoneally and subcutaneously into mice. The cells inoculated intraperitoneally grew vigorously and could not be distinguished, upon cytological examination, from the original ascites tumor of the mouse. The ascites cells injected subcutaneously, failed to produce a tumor, even after 3 months.

ALLANTOIC FLUID

From 8 to 14 million Krebs ascites cells were injected into the allantoic fluid of an eight-day embryo. The eggs were then opened on the 18th day of incubation. Samples of allantoic fluid were withdrawn

with a needle and syringe and aceto-orcein smears were made. Material separated from allantoic fluid by centrifuge was also stained. In no case was any sign of an ascites cell found.

CONCLUSION

The Krebs 2 ascites tumor can be grown in the chicken egg; however, it is not very suitable for the continuous growth of this tumor. This seems to be due to some specific growth requirements inherent in the Krebs tumor that are not present in many other rapidly-growing tumors which do grow well in the egg, e.g. mouse mammary carcinomas, Walker 256 rat carcinoma, Brown Pearce rabbit carcinoma, etc. Karnofsky (2) reaches similar conclusions for leukemias and lymphomas. Such specificity might explain the difficulties encountered in growing these tumors in a medium other than the original hosts.

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NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

GUST PRE-SENSING DEVICES FOR AIRCRAFT GUST-ALLEVIATION SYSTEMS

BY

RALPH S. BARNABY

Under a contract with the Wright Air Development Center of the U. S. Air Force, Dr. Robert P. Coleman, Mrs. Lucille L. Stefan and Mr. Gilbert S. Stubbs completed recently an 18-month study of means and methods of pre-sensing the gusts into which an aircraft is flying, so that measures may be taken to alleviate the effects of the gusts upon the aircraft. In aviation parlance a gust is any sudden change in velocity or direction (or combination of the two) of motion of the air. The most important effects of gusts on an aircraft are changes of lift of the aerodynamic surfaces with resultant unsteady aircraft motion and variations in the stresses in the aircraft structure. The first effect plays an important part in passenger comfort and steadiness of the craft as a platform for such precision tasks as mapping, bombing, gun and rocket firing; the second has an important bearing on structural design.

To provide satisfactory gust alleviation the horizontal tail surfaces as well as the wings must be equipped with alleviation means. The tail problem, however, is somewhat simpler because of its relatively small area and span.

There are numerous ways the basic lift of an airplane can be varied—by controllable slots, flaps, spoilers, camber-changing devices, and boundary-layer control, to name a few. If one knew the precise structure of each gust as it approached, it would appear at least theoretically possible to meet each with the necessary setting of one of these lift-adjusting devices. It is this information a gust pre-sensing device must supply. Since the operation of any of these alleviation devices takes time, a gust-sensing system in practice must be able to evaluate the magnitude and structure of the gust sufficiently in advance of its impingement upon the wing so that the information may be translated into correctly-timed and measured action of the particular lift-changing (alleviation) device, to match and cancel out the effect of the gust.

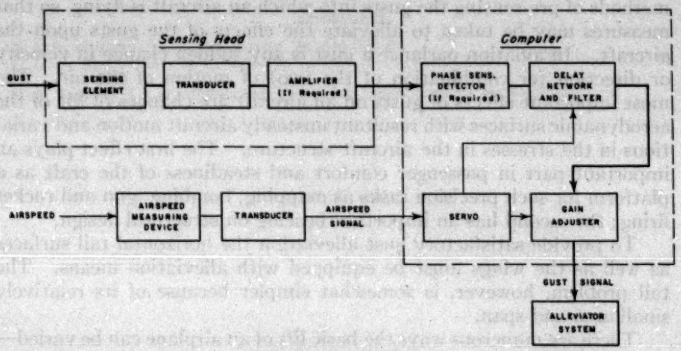
The response time of the alleviation device to an input signal is a characteristic of the device itself, and for a given device will be constant.

The time interval, however, between the sensing of the gust and the required alleviating action depends upon the pre-sensing distance (the

distance of the sensing device ahead of the lifting surface) and upon airspeed of the aircraft. For a sensing device located at a fixed position ahead of the wing this time interval varies inversely with the airspeed.

Since the response time of the alleviator is constant it needs a fixed warning time for successful operation. This may be obtained in several ways. One would be to put the sensing device out far enough ahead to provide adequate warning time for the highest flight speed anticipated, and to delay the signal proportionately for lower airspeeds. Another would be to use a sensing device on a boom whose length could be varied automatically to compensate for varying airspeeds.

In carrying out the investigation it was necessary to study not only the numerous devices which might be used for sensing and evaluating gusts, determining insofar as possible their characteristics and relative



Gust-sensing device.

suitability, but also studying possible computers or filters to modify the signals to provide suitable input information to the alleviation system.

For the purpose of selection and evaluation it was first necessary to develop a method of analysis. This was based on concepts from the field of mathematics called statistical decision functions. The following points were essential to this method:

1. The sensing devices were evaluated on the basis of their contribution to the performance of the over-all system, rather than studied in isolation.

2. Concepts and methods of mathematical probability and statistics were used throughout the problem, especially in the treatment of random errors of the sensing device, and random environment. By random environment in this case is meant the random inputs (gusts). A complete study would include as well (*a*) the distribution of speeds and other

airplane parameters likely to be encountered during the operating life of the device, and (*b*) the distribution of values of parameters of servo-systems, alleviating devices, and other components of a complete alleviation system.

3. The method employed was to obtain general results where possible; to work out a selection of representative special cases; and to indicate the method of working out further cases.

The sensing devices investigated fell into three general groups—those which might sense gusts a considerable distance ahead of the aircraft, those which operate immediately ahead of the aircraft, and those wherein the aircraft's response itself produced the alleviation. Into the first group fell such things as radar and infra red devices: into the second, devices which may be carried on probes of reasonable length attached to the aircraft: into the third, the swept-back flexible wing aircraft.

One of the early conclusions reached was that while equipment of the first group might be able to let the pilot know that he was approaching an area of turbulence, the information would be of too general a nature and too far in advance to provide suitable intelligence to an alleviating system. On the other hand, the third approach, depending on reactions of the aircraft itself could give at best only partial alleviation.

Of sensing devices which might be mounted on probes projecting ahead from the aircraft or mounted within the aircraft, there is a broad field, embracing electrical, optical, aerodynamic, acoustic, thermal and inertial devices. A study of all these indicated that the aerodynamic devices showed the greatest promise, and of these, three appeared worthy of further study and development. Recommended types were a force-measuring model wing and a pressure-difference pitch meter. A freely-hinged vane was also considered worthy of consideration.

A general conclusion was that radical sensing principles were not necessary, but that reasonably conventional types of devices showed the best promise of success. It is believed that the sensing device should be exposed directly to the airstream and thus measure the gust rather than the response of the aircraft to the gust.

The sensing problem is a dual one. First, a decision on the type, sensitivity, and frequency response of the device itself must be made; next the location and number of sensing elements required to evaluate the gust in sufficient time and detail to permit adequate alleviation must be determined.

In modern high-speed aircraft the configuration is generally such that a sensing element located on a boom ahead of the nose of the aircraft will be far enough ahead of the wings to give adequate warning for the operation of the wing gust alleviator, even at the airplane's highest speed. However, such a probe explores and evaluates the gust only along the probe's path, and gives incomplete information on the spanwise gust structure. This will result in erroneous alleviation action.

Where the span is small in comparison with the gust size this may not be too important, but in the case of the modern large commercial transports and military bombing planes spanwise gust information is essential if any high degree of alleviation is to be achieved. Approaching the ideal would be a large number of sensing elements spread out laterally across the full span of the aircraft at a sufficient distance ahead of the wing to provide adequate warning time. The structural and aerodynamic impracticability of such an arrangement is readily apparent. Even the placing of one sensing element at the required distance out in front of each wing would involve booms of impractical length.

In the course of the project a principle involving the use of sensing devices on the nose and also on the wing tips of an airplane was suggested. By using a suitable weighted average signal from all three devices an adjustable effective pre-sensing distance and also an effective spanwise averaging is obtained.

It is hoped that this principle, further developed and implemented, may lead to the eventual development of a practical aircraft gust-alleviation system.

NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, DIRECTOR

NEWCOMEN ATMOSPHERIC ENGINE

At a time when we are expectantly awaiting the development of the means of utilizing nuclear energy for the provision of power, it is instructive to turn back our thoughts to the beginning of the low-powered prime movers that were the heralds of the Industrial Revolution.

The development of the turret windmill in Italy toward the close of the fifteenth century was the last significant addition to the list of prime movers until the invention of the steam engine. During this interval there was some notable inventive work and considerable ingenuity in extending the application of familiar devices, but it was not until the invention of the Newcomen atmospheric engine that anything looking like a steam engine and operating like one was completed.

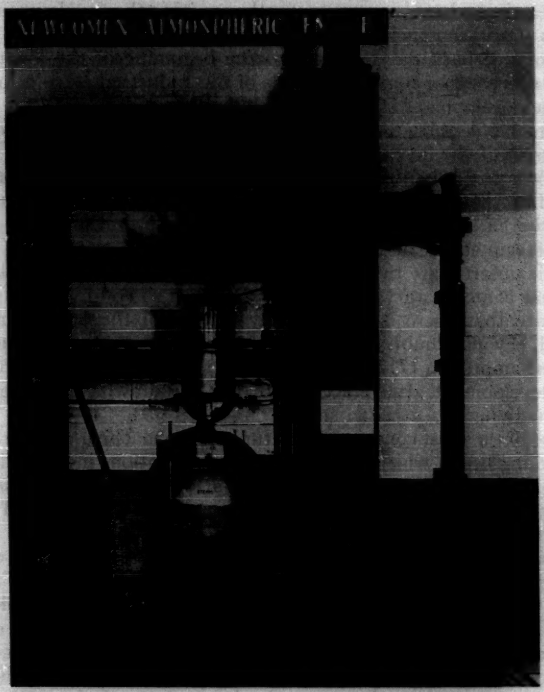
It is unfortunate that the evidence on Newcomen is scant and that the near-contemporary descriptions are often so contradictory and inadequate that there is scarcely any feature of the original machine settled beyond doubt. The first atmospheric engine was built near Wolverhampton in 1712 but it is believed this was subjected to considerable development after erection, so that the drawings represent final construction.

One of the most conspicuous features of the machine was the balance or working beam, which was retained for generations in the condensing engine. To the ends of this beam are attached the piston and pump rods, counterpoised in such fashion as to make the pumping end heavier than the piston end of the beam.

There is no separate condenser. Steam is admitted to the cylinder through a valve and the air in the cylinder is expelled through another valve which opens to upward pressure. As the cylinder is cold much steam is condensed, but as new steam enters from the boiler, the cylinder is soon heated and filled with live steam. An injection cock is then opened and a jet of cold water is introduced which condenses the steam quickly. As condensation proceeds the pressure of air on the piston forces it down, and as the process of condensation continues the descent of the piston is accelerated. Friction and the effect of the counterpoises ordinarily reduced the effective pressure on the piston to 7 or 8 pounds per square inch.

Once the engine is in operation, the rise of the piston is accompanied by a slightly different set of phenomena. When the piston has reached the bottom of the cylinder, the injection cock is closed and the steam valve is opened. The first puff of steam clears the cylinder of any vapor

remaining and creates sufficient pressure to allow the water of condensation to flow off freely. The piston rises by reason of the counterpoises as rapidly as steam flows in, for there is sufficient weight to lift the piston but not enough to create a vacuum. The rise of the piston and the filling of the cylinder with steam are concurrent, although the steam does not exert any pressure against the piston.



This invention marks the effective beginning of the utilization of the new sources of power with which scientists had been struggling actively for about a century. Although the active source of power was the atmosphere, the actual operation turned upon the production of steam. In 1769 Smeaton compiled a list of 99 engines built upon Newcomen's principles, some of which (although they were rare) had cylinders measuring 75 inches in diameter.

The one-quarter scale model of the atmospheric engine in the Museum enables the visitor to obtain an accurate conception of the size and operation of this type of engine.

BOOK REVIEWS

THE CHEMISTRY OF PETROLEUM HYDROCARBONS, VOLUME I, edited by Benjamin T. Brooks, Cecil E. Boord, Stewart S. Kurtz, and Louis Schmerling. 664 pages, illustrations, diagrams, 16 × 24 cm. New York, Reinhold Publishing Corp., 1954. Price, $18.00.

The purpose of this book is to present, in one treatise, the chemistry of petroleum hydrocarbons from the standpoint of the scientific fundamentals involved. The editors have purposely omitted much of the details of processing, analyzing, and testing petroleum and petroleum derivatives because of both enormity of the subject matter and the fact that these subjects are beyond the scope of the book.

The book itself has twenty-one chapters that can be grouped intuitively into four main divisions: (*a*) origin, types, and composition of petroleums, (*b*) methods of separating petroleum components, (*c*) methods for studying the physical properties of hydrocarbons (ultra-violet, infra-red, Raman, and mass spectroscopy), (*d*) synthesis of alicyclic and aromatic hydrocarbons of low and high molecular weights. Each chapter has been prepared by specialists in the particular field, and when some topics are given cursory treatment, ample literature references are supplied for those readers desiring more complete information. In the opinion of the reviewer the most provocative portion of the book was the part devoted to the use of physical methods for predicting the chemical composition of petroleums. In particular, the chapters on the use of spectroscopy to study the composition of complex hydrocarbon mixtures can be singled out as being especially interesting. Spectroscopy is probably the most useful tool available to technologists today for identifying petroleum components and estimating their relative concentrations, hence these chapters are of most immediate and vital importance. There are also several noteworthy chapters on the synthesis of hydrocarbons. They are especially valuable since they present general synthesis methods rather than the myriad of production details that make the literature in the field appear to be so plethoric.

Excellent is the only adjective that adequately describes the preparation and presentation of this volume. The editors are to be congratulated on their ability to sift out the scientific fundamentals from the rapidly pyramiding field of petroleum technology. This book provides the only complete up-to-date source on basic petroleum chemistry, and no chemist, physicist, or engineer connected with either the production or use of petroleum and petroleum derivatives can afford to be without this book.

D. H. RUSSELL

SELECTED PAPERS IN STATISTICS AND PROBABILITY, by Abraham Wald, edited by the Institute of Mathematical Statistics. 702 pages, 18 × 26 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $8.00.

The number of scientific papers published by a scientist is the yardstick whereby his stature is judged; this has been true since the days of Euclid and Hippocrates. Today, for example, the post-doctoral progress of a mathematician and statistician is evaluated by his peers in terms of how many contributions he has made to professional journals. Few authors publish papers regularly; still fewer publish papers of a profound nature. Abraham Wald, without any doubt, belongs to the latter category. His meteoric rise and his contributions to mathematical statistics are matched by few: In the short span of nineteen years, Wald published 104 papers and books! The most important of his collected papers are now published—only five years after his untimely demise—and the important rôle which he has played in the field of mathematical statistics is thereby acknowledged.

The present volume contains fifty of Wald's published papers and his hitherto unpublished address to the International

Congress of Mathematicians at Harvard in 1950. The volume opens with a discussion of these papers. Most important of course is the field of Statistical Decision Function Theory and Sequential Analysis. Sixteen of the collected papers trace the growth of Wald's insight into various aspects of this activity. Among these are his "Contributions of the Theory of Statistical Estimation and Testing Hypotheses" (1939) which first defined the problem and introduced the minimax principle. Even at this early stage, Wald thought of leaving some of the choices to chance and considered a number of special cases where randomization can be avoided. The construction of usable sequential procedures is exemplified by a number of his papers written before or after his epoch-making "Sequential Analysis" appeared. His research led him on to evaluate the performance characteristics of these sequential methods of taking observations and to determine optimum (including minimax) solutions of specific decision problems. His address to the International Congress of Mathematicians in 1950 contains an outline, in his own words, of the main ideas and is illustrated by cases involving a finite number of decisions.

During his formative years, Wald wrote a large number of papers, mostly in German, on measure theoretical aspects of convex sets and probability. Of these, only "Die Widerspruchsfreiheit des Kollektivbegriffes" (1938) is reprinted here. Later papers on Probability demonstrate Wald's remarkable mathematical skill which led him to generalize earlier studies of Tchebychef, Markoff, Stieltjes, and others, and to obtain complete solutions of long outstanding and intricate problems.

A third group of nine papers presents Wald's thinking on Non-Parametric Inference. This field has received considerable attention since 1940 because of the increasing demand for tests which do not require the assumption of normality. As early as 1939, Wald investigated confidence belts for distribution functions, only to learn that this work had already been done by Kolmogoroff. Undaunted by such ill luck, Wald continued his work and studied asymptotic normality of certain test criteria based on permutations of the observations as well as some non-parametric tolerance limits suggested by Fisher.

The Theory of Testing Hypotheses and Estimation is exemplified by eight papers, four of which were published in the early 1940's. Wald devised here his own definitions of optimum performance for a sequence of tests: Best constant power, best average power, and most stringency of a test. Analysis of Variance exhibits four papers in which Wald treated the problems of variance component analysis with increasing generality. Eight papers on Other Topics prove the versatility of Wald's genius which caused him to penetrate deeply into many different classes of problems. Among others, he considered stochastic difference equations, conditions for identification of parameters, sampling inspection plans, and multivariate fitting problems.

The dramatic impact of Abraham Wald's prolific contributions to mathematical statistics will be felt by all who use this important tool in research. The present publication of his most important papers makes practically all of his contributions to mathematical statistics available in book form. It also lends a new perspective to his work by relating his different papers to each other and to the work of others. The book was made possible by the joint efforts of the many societies that gave permission to reprint his papers in this form. It was assembled under the sponsorship of The Institute of Mathematical Statistics and the Committee on the Wald Memorial Volume. In conjunction with the volumes written and published by Wald during his lifetime, it is an important source for students and researchers in mathematical statistics. CARL HAMMER

GLASS REINFORCED PLASTICS, edited by Phillip Morgan. 248 pages, diagrams, illustrations, and charts, 15 × 25 cm. London, Iliffe & Sons, Ltd.; New York, Philosophical Library; 1954. Price, $10.00.

This book is badly needed in a growing field of many potentialities. It has been written for the general reader but goes into sufficient detail to be of immediate interest to the specialist in the field. It has been compiled by a large number of known experts of the English Plastic Industry and covers

such diverse subjects as resin chemistry and production molding methods. The different chapters are largely self-contained and can be read by themselves. This of course, causes some repetition which, however, should be considered as an asset rather than a shortcoming, if one recognizes the main objective of this book.

The interest is first focused on fiberglas and on its many forms in which it is met in reinforced plastic.

Then the book leads the reader into the chemistry of unsaturated polyesters and allyl resins, discusses the various polyester types and their properties, and brings a complete chapter on the ancillary materials such as catalysts, accelerators, fillers, release agents, pigments, and inhibitors.

The use of phenolic resins with fiberglas, dating back further than the use of any other resin, gives widely different types of products. At the present stage polyesters are the most generally used resins. However, continuous attempts to make laminates which show an improved performance in specific fields as heat resistants and dielectric strengths has led to the use of silicones and epoxide resins.

In a chapter on commercial molding processes, the single mold technique, the pressure bag technique, mating mold technique without pressure, and pressure molding using matched tools are described. In deciding upon the molding operation the question of the intended property of the article and the cost to produce it are of primary importance.

While articles might be produced easily in small numbers, mass production first makes them competitive. Consequently some methods of mass production are expounded.

One field of great promise for fiberglas reinforced plastics is the tube and rod production. Here the production of glass as continuous filament facilitates the orientation of the reinforcement in molding and laminates which is a definite advantage in the production of tubes and rods.

Following a chapter on the design and properties of structures, the last part of the book is devoted to the many fields of fiberglas reinforced plastic applications, such as aircraft industry, electrical industry, automobile body work, transportation industry, boat building, and many other applications.

All of the fifteen chapters are followed by extensive literature references well documenting the presented material. The book is surely a step forward to put this rapidly advancing new field on a firm technical basis.

KARL SITTEL

HIGHER TRANSCENDENTAL FUNCTIONS, VOLUME III, edited by A. Erdèlyi. 292 pages, 16×24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $6.50.

This is the final volume of a three-volume series on advanced mathematics. It has six chapters numbered to succeed the thirteen chapters of the first two volumes and provides us with functional relationships, microscopic and macroscopic behavior of the functions, and valuable literature references.

Chapter XIV presents the automorphic functions. It begins with the necessary definitions which lead to the various types of homographic substitutions and the finite or infinite groups which characterize the functions. Chapter XV treats Lamé and Heun's Functions and includes some results obtained recently by Erdèlyi for the solution of the general Lamé Equation. The next chapter deals with Mathieu Functions, Spheroidal and Ellipsoidal Wave Functions. It includes a section on modified Mathieu Functions, as well as approximations and asymptotic forms for both Mathieu Functions and Spheroidal Wave Functions. The seventeenth chapter treats some of the functions arising in Number Theory, including the interesting functions of partition theory and associated generating functions. Chapter XVIII introduces Miscellaneous Functions derived from certain differential equations; included are Mittag-Leffler's Function and higher order trigonometric functions which satisfy $d^n y/dx^n + y = 0$. The last chapter elaborates on the earlier introduced generating functions; it begins with a section on general properties and closes with a survey of relationships connecting the transcendental functions described in the three-volume series.

The amount of information presented in this volume alone is very impressive: More than 1100 numbered functional relationships and over 500 references are listed in connection with six chapters. No other tables of a similar scope provide so much information

on these frequently needed functions. The compilation is a lasting monument to the memory of the late Harry Bateman and a credit to the Editor, Professor A. Erdélyi, and his Research Associates, W. Magnus, F. Oberhettinger, and F. G. Tricomi.

CARL HAMMER

TRANSISTOR AUDIO AMPLIFIERS, by Richard F. Shea. 219 pages, diagrams, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1955. Price, $6.50.

The subject matter, which follows very closely the title of the book, is introduced with a discussion of the basic transistor types and graphical methods for representing their characteristics. The author then proceeds to show how these characteristics naturally dictate the transistor's circuit behavior. The seriousness of temperature influences in transistor operation is stressed early in the presentation so that this important effect will not be overlooked by the circuit designer who is used to the relative temperature insensitivity of vacuum tubes. This question then leads to the subject of stabilization arrangements which are required for satisfactory operation in practical electronic devices.

Most important to the engineer is the introduction of equivalent circuits and a study of the interdependence of the various transistor parameters. All of this material is illustrated graphically and quantitatively. It is further supplemented by a valuable section in the middle of the book containing tables of data for individual General Electric, Raytheon, and other manufacturers' transistors. The data given here are fully as complete as the corresponding information in vacuum tube manuals.

One finds flexibility in the application of transistors as circuit elements somewhat akin to the grounded-grid, self-bias, and cathode-follower arrangements of the vacuum tube. That is, each of these connections employs a different group of analytical expressions, and in like manner Mr. Shea develops for the various transistor connections, grounded-base, grounded-emitter, grounded-collector, the appropriate analytical expressions.

These methods are then applied to the design of coupled stages and to conventional "class" amplifier operation. Noise figure, frequency considerations, clipping, and numerous refinements of amplifier design are provided together with numerical examples. Finally, designs of practical amplifiers are worked through for the benefit of the reader who may wish to become acquainted with some of the details of current practice.

Only positive comments can describe this book by Richard Shea, for it has the same enduring qualities of certain earlier books on communications, Everitt, Terman, Reich, and others. In spite of the newness of transistors it is likely that Shea's presentation will withstand the test of time because of its fundamentally analytical approach to the subject. Specialization in material of carefully limited scope, audio amplification, has permitted a thoroughness of treatment which makes the book of real value to the practicing engineer. The volume should be welcomed by the profession because of its solid, meaningful engineering content.

C. W. HARGENS

SONICS, by Theodor F. Hueter and Richard H. Bolt. 456 pages, diagrams, illustrations, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1955. Price, $10.00.

Sonics as used in this book refers to the analysis, testing and processing of materials and products by the use of mechanical vibratory energy. In particular, it is the technology of sound as applied to problems of measurement, control and processing. Prior to World War II the word "sonics" referred almost always to available sound or hearing. As a result of the development of military devices and auxiliary electronic techniques, the application of sonic frequencies to a host of industrial problems is gradually changing from a highly skilled art to somewhat of a science. It is, therefore, heartening to welcome the book under review. It draws its material from the fields of physics, electronics and engineering, and applies the necessary principles, techniques and instrumentation methods to a number of industrial processing and analysis applications.

Three spheres of interest are developed in the book: basic principles of sound energy; energy transducers; and applications. Conciseness, brevity, and to some extent an heu-

ristic approach to the basic principles of sound radiation, and scattering characterize the opening chapters. This is necessary because of the large amount of background material which must be understood by one who is to apply sonics to some practical uses. Piezoelectric and magnetostrictive transducers are discussed in a detail not previously found in other books and only partially in the published literature. Several designs developed by the authors are described, so that the reader may, if necessary, attempt his own designs with a fair degree of ultimate success.

Space does not allow an enumeration of the details of the four chapters devoted to analysis and processing applications. The first class of applications requires low power primarily for the measurement of physical properties of a medium (flaw detection, determination of molecular properties, viscosimetry, etc.). The second class requires high power to modify the medium in some way (degassing, emulsification, changing viscosity, etc.).

This reviewer is of the opinion that *Sonics* fills a void which has existed for several years. It should be of primary interest to practicing engineers and physicists who are in any way concerned with industrial processing, measurement, and control. Needless to say, it should serve well as a reference book of this subject. S. CHARP

ENGLISH-GERMAN TECHNICAL AND ENGINEERING DICTIONARY, by Louis DeVries. 997 pages, 16 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $20.00.

The author is well known for his successful *German-English Technical and Engineering Dictionary*. This new volume was planned to supplement the former, to facilitate back translations, and to improve communications in technical fields which coin new words at an ever increasing and unprecedented rate. A technical dictionary on a broad basis is sorely needed as attested by the fact that there exist over fifty smaller, more or less specialized English-German technical dictionaries. Political developments of the last twenty years have added to the importance of communications in these two languages and have caused a steady increase in the output of such dictionaries.

Professor DeVries prepared this newest dictionary from 85 reference works with the aid of 76 collaborators here and abroad. The result is an impressive volume with more than 130,000 entries on about a thousand pages. This dictionary is not intended to replace existing general dictionaries; it will supplement them superbly. Therefore, it does not contain phonetics, accents, or any aids to pronunciation. The stress is placed on content, technical competence, and broad treatment of scientific fields.

Sampling of the contents shows that most technical subjects are well covered. Among the engineering fields we find: aeronautical, automotive, chemical, civil, mechanical, mining, soil, and electrical engineering (including radio, television, and electronics). Other subjects given broad coverage are: inorganic, organic, and biochemistry; physics, geology, metallurgy, textiles, military terminology, navigation, and communications. Although the emphasis is on engineering, we find also many terms from mathematics, statistics, medicine, and numerous other fields.

The author has paid heed to more recent developments in the German language. First of all, the double "s" at the end of words or syllables is written out rather than in form of the ß. This is modern usage but causes some minor difficulties in words having thus a triple consonant (cf. page 530, *measure, Massstock*). Generally, the user of this dictionary is expected to understand such details. Second, the author has noted the recent trend to eliminate or replace words with Latin or Greek roots from the German language. This trend has added to the picturesqueness of the language but has also made technical German more difficult to read. Not listed are monstrosities created during the middle thirties, such as *Four Cylinder Explosion Engine: Viertopfzerknalltreibling;* however, *stoichiometry* is listed only as *Elementenmessung* without reference to the more customary *Stöchiometrie*.

The gender of nouns is usually indicated by m., f., n.; occasionally these symbols are missing, possibly in error, or are subject to misinterpretation as they were inserted into the middle of compound phrases (cf. page 301, *equatorial system*). Other grammatical

details are not supplied but a long list of abbreviations is used to indicate special vocabulary. On occasion, the German word given first is not the most frequently used (cf. page 148, *circle*).

The dictionary presents also some evidence to the effect that both languages have reached a high state of specialization and relative conciseness which can cause some awkwardness in the translation. For example, on page 177, *Computing Slide Rule for Transfer of Sound- and Flash-Ranging Data to Control Chart* becomes simply *Auswertelineal.*

Efficient use of any dictionary is facilitated by a good choice of print type and of binding. This volume rates an "excellent" in both respects. The bold type English words stand out clearly against the light face type German equivalents. The binding is flexible buckram and the volume will rest open, in any page position, without the pages turning by themselves. This first edition contains some misprints which any versed translator will spot at once. These minor blemishes are likely to be corrected in future editions. Taking everything into account, this dictionary will serve its intended purpose well. It will render valuable assistance to those engaged professionally in technicai translations from English to German.

CARL HAMMER

EXISTENCE THEOREMS FOR ORDINARY DIFFERENTIAL EQUATIONS, by Francis J. Murray and Kenneth S. Miller. 154 pages, 16 × 24 cm. New York, New York University Press, 1954. Price, $5.00.

This book develops the fundamental existence theorems for ordinary differential equations which have great importance in modern analysis. The classical approach to the subject is followed; the existence theorems, except those on linear differential equations, are theorems "in the small," that is, concerned with solutions in a neighborhood around an arbitrary point. The modern theories "in the large" of Poincaré and the later researchers are omitted. A knowledge of basic real variable theory and elementary complex function theory is assumed.

The fundamental Peano existence theorems for a single equation and for n equations are stated and proved in the opening chapter. There follow general existence theorems; the implicit function is stated and proved; it is then used to convert implicit equations to forms for which the Peano theorems apply. Chapter 3 covers uniqueness theorems which may be used in conjunction with the existence theorems. The importance of a Lipschitz condition in establishing uniqueness of solution is stressed. The Picardi iterant methods are developed in Chapter 4 and applied to prove existence and uniqueness of solutions. The Picardi existence theorem is also proved via the same process.

The dependence of solutions on initial conditions and parameters, and the properties of solutions in these variables are thoroughly treated. The conditions for differentiability and analyticity of solutions in the initial conditions and parameters are established. A concluding chapter covers important theorems "in the large" for linear differential equations.

The proofs are detailed and rigorous throughout the text; they are addressed to the student of this subject rather than to the casual reader. Real variable theory concepts such as equicontinuity and the Lipschitz condition are introduced wherever they are needed in the proofs. The authors emphasize the importance of machine methods of calculating the solutions, and their relations to the existence theorems given here. The book is quite suitable for an introductory graduate course in this subject.

HOWARD H. BROWN

PHYSICAL MEASUREMENTS IN GAS DYNAMICS AND COMBUSTION, edited by R. W. Ladenburg, B. Lewis, R. N. Pease and H. S. Taylor. 578 pages, illustrations, 16 × 24 cm. Princeton, Princeton University Press, 1954. Price, $12.50.

This book is Volume IX of the set of twelve volumes on "High Speed Aerodynamics and Jet Propulsion" of the Aeronautics Publication Program at Princeton University. The Board of Editors consists of Theodore von Kármán, Chairman, Hugh L. Dryden, Hugh S. Taylor, Joseph V. Charyk (who served as General Editor 1951—) and Martin Summerfield (General Editor 1949–1951).

This volume records the variety of techniques which can be employed to measure density, pressure, velocity, and temperature in gaseous systems. It deals with the measurements of shock waves, turbulence, condensation studies, and analog methods. The second half of the volume is concerned with techniques for the measurement of properties in materials undergoing combustion processes.

Each section constitutes an authoritative explanation of the physical principles underlying a particular type of physical measurement in gas dynamics. For example, under density measurements, there is a section on the analysis of optical methods in which the general principle of geometric optics, in the form of Fermat's law of stationary transit time is first introduced. Then the principal types of optical systems to study patterns of density variation are briefly described in a way to point out the differences between the shadowgraph, interferometer, and schlieren arrangements. Quantitative methods of analysis of different systems are then presented in greater detail and with numerous references. The emphasis here as well as throughout the book is on physical principles of operation more than on descriptions of apparatus. This section is followed by detailed discussions of shadow and schlieren methods, interferometry, electrical discharge and afterglow technique, spectral absorption method and the X-ray technique.

Other sections cover the principles and techniques in other types of physical measurement in similar detail.

This volume of 578 pages is remarkable for the large amount of information contained in it, and for the clarity of exposition. It should be of great value to students and research workers in the fields covered.

ROBERT P. COLEMAN

ALTERNATING-CURRENT AND TRANSIENT CIRCUIT ANALYSIS, by Harris A. Thompson. 317 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $6.75.

Textbooks suitable for use in introductory courses in electric circuits are many and varied. It is indeed difficult for any author to bring something fresh into a subject which is today almost as standardized as an introductory course in geometry. The author of this book has unfortunately, in the opinion of this reviewer, produced "just another textbook" for a first course in alternating currents. The volume contains standard material, ordered in the traditional manner, with even no new methods of presentation to justify its entry into the already too long list of books which overcrowd the field. Suffice it to say that the book is an introductory one on the fundamental concepts of practical steady state circuit analysis, suitable for a junior level course in alternating current circuits for electrical engineering students.

Thus the book includes chapters devoted to elementary circuit concepts, complex algebra and phasers, solutions for current, voltage, and power in simple single phase and polyphase circuits, network theorems, nonsinusoidal periodic waves, elementary transient analysis of simple circuits, and mathematical analogues. Since but one chapter out of ten is devoted to transient analysis, it is seemingly improper to entitle the book *Alternating-Current and Transient Circuit Analysis*. Contrary to the presently accepted standard use of the rationalized mks system of units, the author uses the mks system and the former where necessary. This, it seems, is out of place for a modern textbook for engineering students.

One feature of the book is the inclusion of about 500 problems of varied difficulty, certainly a sufficient number to keep any junior student busy for the period of this course.

S. CHARP

MECHANICS FOR TEXTILE STUDENTS, by W. A. Hanton, 336 pages, diagrams, 14 × 22 cm. Manchester (England), The Textile Institute, 1954. Price, 25/ ($3.50).

This studybook is specifically designed for both teacher and college student or textile institute student and is not a textbook in the accepted sense. Also it is of great value for foremen in textile mills.

Emphasis has been placed on textile machines and processes as related to the movements of machine parts. The book is unusually well illustrated. The explanations are most complete and clear. In addition, the mechanics presented should interest all students of textile machinery developments,

who wish to acquire a thorough understanding of mechanical forces at work in textile machinery. CAROLINE BOYER

WORSTED DRAWING AND SPINNING. Part I: DRAWING, by H. Walker. 239 pages, illustrations, diagrams, 14 × 22 cm. Manchester (England), The Textile Institute, 1954. Price, 21/ ($3.00).

This book is a successful attempt to bring-up-to-date an important phase of worsted processing. The processing of wool on the worsted system has been a standard operation for decades.

The author achieves an excellent result in setting forth in clear language the processing developments and modifications of the past decade but also includes helpful drawings and pictures of the various textile machines used for processing. These should be of great interest to engineering students as well as textile institute students.

CAROLINE BOYER

REVIEW OF TEXTILE PROGRESS, VOLUME 5. 588 pages, 14 × 22 cm. Manchester (England), The Textile Institute & The Society of Dyers and Colourists, 1954. Price, 35/ ($5.00).

This is Vol. 5 and continues to record significant advances of chemical progress in the textile history in Great Britain. This volume, as well as the previous four, are worthwhile additions to the library of all textile institutes. In addition textile technologists, chemists, and chem-engineers related to textile activities should consider this compilation of papers published jointly by The Textile Institute and The Society of Dyers and Colourists a very valuable reference. It includes quite a range of subjects from "Physics and Chemistry of Fibrous Materials" to the "Colouring of Textiles" and "Industrial Applications of Textiles."

CAROLINE BOYER

PUBLICATIONS RECEIVED

EPHRAIM'S INORGANIC CHEMISTRY, edited by P. C. L. Thorne and E. R. Roberts. Sixth edition, 956 pages, diagrams, 17 × 25 cm. New York, Interscience Publishers, Inc., 1954. Price, $6.25.

DIFFERENTIAL AND INTEGRAL CALCULUS, by Harold Maile Bacon. Second edition, 547 pages, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $6.00.

MATERIALS OF CONSTRUCTION, by Adelbert P. Mills, Harrison W. Hayward and Lloyd F. Rader. Sixth edition, 650 pages, illustrations, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1955. Price, $7.50.

ELEMENTS OF RADIO SERVICING, by William Marcus and Alex Levy. Second edition, 566 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. No price.

PHILOSOPHY AND ANALYSIS, edited by Margaret MacDonald. 296 pages, 15 × 22 cm. New York, Philosophical Library, 1954. Price, $7.50.

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CURRENT TOPICS

A miniature electronic "brain" that opens a new era in computers, and that can operate flawlessly in planes flying at supersonic speed, has been developed for the U. S. Air Force by Bell Telephone Laboratories.

The "brain," a digital computer, eliminates vacuum tube failure and heat, jet aircraft's greatest electronic problems, by the use of transistors instead of vacuum tubes. It contains nearly 800 of these tiny, solid devices and is believed to be the first all-transistor computer designed for aircraft. Transistors, invented at Bell Laboratories, are completely cold, highly efficient amplifying devices which use very little power.

The new computer, known as TRADIC (TRAnsistor-DIgital-Computer), requires less than 100 watts to operate. This is one-twentieth of the power needed by comparable vacuum tube computers. Early computers used as many as 18,000 vacuum tubes and frequently required thousands of watts to operate.

The new electronic "brain" contains, in addition to transistors, nearly 11,000 germanium diodes. These serve as the electronic equivalent of tiny one-way switches. Solid, like transistors, they are capable of operating thousands of times faster than their mechanical counterparts.

When design work has been completed, the computer will probably occupy less than three cubic feet of the critical space in modern military aircraft.

The new general purpose computer was developed at Bell Laboratories under the direction of J. H. Felker, an electrical engineer. Mr. Felker is in charge of a group of electrical and mechanical engineers developing transistor circuits for military applications.

Tradic can do sixty thousand additions or subtractions, or three thousand multiplications or divisions a second. A typical problem fed into the machine requires it to go through about 250 different steps of computation. It can run through an entire problem of that complexity and provide an answer in about 15 thousandths of a second—much less time than it takes to say "Tradic." The computer can handle, simultaneously, as many as thirteen 16-digit numbers.

Mathematical instructions are placed into Tradic by means of a "plug-in" unit resembling a small breadboard. Plug-in units are set up beforehand with interconnecting wires to represent problems at hand. Numbers to be processed are put into the machine by means of simple switches.

The laboratory model of Tradic provides answers to trigonometric problems with a series of "dots" on an oscilloscope. These dots of light move so rapidly that they actually appear to draw geometric diagrams on the scope.

To handle the successive steps of complex computation, a machine, like a human, must have a means of storing information until it is needed. When a man works on an involved mathematical problem, he usually jots down on paper the answer to each section as it is solved, then refers back to this frequently as he proceeds. Tradic, however, automatically transfers each sub-answer to built-in "memory" packages while continuing to tackle the remaining sections.

There are two main types of computers, digital and analog. A digital computer, like the mileage indicator of a car, is a "counting" machine which clocks off one number after another. Each digit shifts when the number to the right of it passes nine. Digital computers can actually perform only additions or subtractions but they are able to multiply or divide by successive additions or subtractions.

An analog computer might be likened to an automobile speedometer which represents speed in terms of the angle of a pointer on the dial. An analog computer gives results in terms of voltages, resistances or rotations. It is designed for a specific task and cannot be easily adapted for another problem.

Tradic, fundamentally a digital computer, has the advantage of being able to operate on analog data.

New Miniature Commutator-Generator.—The Computer Instruments Corporation of Brooklyn, N. Y., announces the introduction of the Precision Commutator and Impulse Generator, as a standard component in their integrated line of miniature precision potentiometers. This unit is intended for use as a high speed switching device for counting, digital indication of shaft rotation, pulse shaping, pulse gating, sequence circuit control, and the like.

The Commutator-Generator consists of a series of conducting segments, bonded to a high temperature plastic base, insulated from one another, and interconnected to form a wide variety of coded commutation or pulse sequences. The use of multiple isolated wipers permits commutation in several circuits simultaneously, and increases total pulse count per revolution. The commutator element can be nested with standard C.I.C. potentiometer elements for various analog-to-digital conversions, potentiometer excitation control, pulse shaping, and similar applications.

The element is approximately 1 in. in diameter and weighs $\frac{3}{10}$ oz. Precious metal contacts are employed throughout. Operational speeds up to 1000 rpm. are permissible, with a life in excess of one million revolutions. The commutator element is available either unmounted or in a precision end bell assembly with ball-bearing supported shaft for extremely low torque operation.

Silicone Cloth for Film Treatment.—Once again science comes to the aid of the camera fan and the owner of record collections. Colorless Silicones (called the "wonder chemical" by industry) have been impregnated into a soft, scratchless flannelette to provide a waterproof and dirt-resistant coating when applied to film and equipment surfaces. The cloth is also used on records and recording tapes.

Silicones are non-toxic, odorless and non-evaporating, and are harmless to negative or positive film. Lenses, metal or leather surfaces—in fact any polishable surface—take on added lustre when coated with lubricating silicones.

FilMagic Cloth, as it is called, comes in a 12 by 18-in. size, and is available at camera stores. The cloth can be washed again and again without losing effectiveness. The manufacturer claims that one FilMagic Cloth will save many times its cost in film treatment fluids alone.

For a sample swatch and useful instructions (both free) write The Distributor's Group, Inc., 756 West Peachtree Street, N.W., Atlanta, Georgia.

High Speed Mercury Jet Commutating Switch.—A high speed commutating and sampling switch for monitoring 120 circuits 60 times per second

is available as a recent development of the Detroit Controls Corporation, Research Division, Redwood City, California. This switch utilizes a unique contacting technique. It employs a mercury jet stream continuously emanating from a central pool (the pole of the switch) contained in the rotor of the switch. This jet stream is caused to sequentially contact pins located circumferentially around the stator, thereby electrically connecting each pin in succession to the pole.

In addition to its high sampling speed, this switch is characterized by a lack of contact bounce phenomena, by a low noise level in general, and by the potential of hundreds or thousands of hours of continuous trouble-free operation.

This switch was originally developed in conjunction with a telemetering system for the University of California Radiation Laboratory, Berkeley, California. The system employs a method of electronically synchronizing two such switches remotely situated (i.e., not mechanically coupled by virtue of a common drive shaft).

The method used employs two 60-cycle synchronous motors which run at identical speeds. The motors are kept in an exact and particular phase match by controlling the phase of the power supplied to one of the switches. Phase match to less than 5 microseconds is accomplished in this fashion.

Four-in-One Radiation Detector.—A new lightweight portable probe which selectively detects alpha-beta-gamma and thermal-neutron radiation has been developed by the General Electric Company's Instrument Department.

According to G-E radiation instrument engineers, the new device features interchangeable heads for detecting different radiations, extremely high thermal neutron counting efficiency, and the ability to count alpha particles in the presence of high beta-gamma background.

In the portable radiation probe, scintillation caused by radiations is detected by a 5819 photomultiplier tube. The output is fed to a high-stability, cathode follower pre-amplifier which operates directly into almost any scaler. A standard connector at the rear of the probe allows connecting cable to be attached to the probe.

The phosphors for detecting alpha, beta, gamma, and neutron radiations are incorporated into specially designed caps. These detecting heads can be quickly interchanged. Should the need arise, the various phosphors in the caps can be easily replaced.

Incorporation of the scintillation counter as the basic detecting unit contributes to the instrument's high overall efficiency, fast response time, and long life. Fast scanning is possible with the portable probe because of its extreme sensitivity—about 25,000 counts per minute per mr per hour from radium gamma rays.

Application of the new instrument is expected to be found in industrial and university laboratories, and hospitals now working with radioactive materials.

It measures 2⅜ in. in diameter and including the gamma cap is approximately 15 in. in length. The instrument's approximate shipping weight is 10 lb.

Fluxless Soldering of Small Parts.—For fluxless soldering of wires, small parts, and the repairing of aluminum castings, Aeroprojects has released another hand model of SONOBOND. This unit is light and very easy to handle. The ultrasonic soldering head is 8 in. long and weighs only 10 oz.

Although small, it has ample ultrasonic power in its ⅛-in. diameter tip to tin aluminum, copper, brass, magnesium or silver very rapidly. The heat required for soldering is supplied by a 600-watt platen.

SONOBOND Model No. S-1-H-54-12 includes the ultrasonic generator, heating platen, and ultrasonic soldering head.

Aeroprojects, Inc. is located at West Chester, Pa.

Electrographic Recording.—Development of a new super-speed process called "Electrographic Recording" which will print lightning-fast calculations of an electronic "brain" at the rate of 5000 characters a second, has been revealed by Burroughs Corporation. The new printing technique was described by Dr. Herman Epstein of Burroughs Research Center at the recent West Coast Computer Conference in Los Angeles.

Potential applications for Burroughs electrographic printing technique include: (1) electronic computer output systems; (2) high speed labeling or strip printing; (3) page printing; (4) teletyping and telemetering applications; (5) facsimile and duplicating applications; and (6) display applications.

The current laboratory model is being used as a basis for further research into the development of this new art and for exploring its full potential for business, industrial, and governmental use.

Dr. Epstein told the scientists and engineers at the conference that it is essentially a three-stage operation. Characters first take the form of a pinpoint pattern of electrostatic charges on the surface of a low cost coated paper. Next, the pattern is made visible by passing the paper through a dry ink bath. Here, tiny particles of powdered ink cling to the pinpoint areas where the paper has been charged. The paper then rolls through a third station where a temperature controlled hot plate "fixes" the ink permanently, making it fade proof and smudge proof.

The paper moves continuously through the three stations at a steady rate of speed up to 44 ft. per second. The end result, according to the Company, is a line of uniform, clearly visible printed characters with virtually no background discoloration.

The initial electrostatic image of each character is created by passing a short burst of electric current through selected wires in a 7×5 matrix. Each image is formed on the paper in three millionths of a second. The selection of the proper wires to form successive character patterns is carried out electronically by an encoder which reads punched paper tape, magnetic tape or punched cards, or translates directly from an electronic computer.

All components of the present laboratory model are small enough to be enclosed in a cabinet approximately the size of a two-suiter travelling bag.

Power requirements necessary to print at the rate of 5000 characters a second are only 5 watts, in addition to those needed to move the paper.

Mechanically and electronically, the components are simple and low in cost. The only moving parts are those necessary to keep the paper in continuous high speed motion. Operation is silent except for the sound of moving paper.

The present model, which uses a single print head to create a single line tape, is capable of being expanded to include a number of print heads. This expansion would multiply the present output of 5000 characters a second by the number of print heads added.

Klystron for Airborne Radar Applications.—A new, low-cost reflex klystron, the VA-203, featuring superior frequency stability for airborne X-band radar receiver and beacon local oscillator service has been introduced by Varian Associates of Palo Alto, California.

Claimed to be the most advanced klystron ever developed for airborne applications, the VA-203 features a unique, brazed-on external tuning cavity to assure exceptional frequency stability. The new klystron is able to withstand shocks of 50 to 100 *g*'s without malfunction or damage. Among its exclusive characteristics are negligible microphonics, slow tuning rate, long tuning life and a single shaft tuner which adapts easily to motor tuning. Weighing only eight ounces, the low-cost VA-203 mates directly to standard wave guide flanges.

In connection with the introduction of the VA-203, the manufacturer has announced a companion klystron—the VA-201—for super-rugged service. Equipped with silastic leads, the VA-201 klystron resists shocks as high as 250 *g*'s and performs with the same dependability as the VA-203.

Improved Recording Spectrophotometer.—A recent development in the Cary Model 14 Recording Spectrophotometer has opened a new wavelength region which will permit analysis of a number of compounds not previously adaptable to ultraviolet spectrophotometry on standard instruments, according to an announcement from the Applied Physics Corporation, Pasadena, California.

Through the use of optical elements of increased ultraviolet efficiency in the prism grating double monochromator, the improved Model 14 provides good performance to 1900Å and even shorter wavelengths. This region includes analytical possibilities for ketones, alcohols, mono-olefines, aromatics and several other compounds. Formerly, good performance below 2100Å was possible only on custom-made instruments.

Although the prism grating double monochromator of the Model 14 has been known for its unusually high resolving power with low scattered light (less than a part per million) in the ultraviolet, visible and near infrared regions, the improved optical elements make it even more effective and provide the extended range, according to the company.

Houdriforming Catalyst to be Made in Europe.—Houdriforming process licensees in Europe shortly will be able to obtain catalyst supplies made on the continent, Houdry Process Corporation has announced. An agreement has been signed with the Chemische Werke Huels A. G., at Marl, Kreis Recklinghausen, (W) Germany, under which the Huels plant will produce catalyst for use of European Houdriforming licensees. Houdriforming catalyst manufactured by Huels, under the agreement, may also be sold to other refineries under appropriate licensing arrangements with Houdry Process Corporation. Up to now, the only source of Houdriforming catalyst had been the Houdry plant at Paulsboro, New Jersey.

Army's Bulldozer Remodeled.—They're making some changes on the Army's bulldozer and "grease monkeys" are glad! The Corps of Engineers' Research and Development Laboratories, Fort Belvoir, Virginia, have undertaken a program designed to make work a lot easier for heavy equipment mechanics who have to keep the construction engineer's best weapon in top shape.

Through field reports compiled during the past few years, laboratory engineers have been able to determine the parts which give maintenance crews most trouble. They are now modifying these parts, along with neighboring components, to facilitate rapid repairs.

Excellent results have already been accomplished in tests of a hydrajuster, a device which allows adjustment of the bulldozer's track with a standard grease gun. On the standard D7 tractor, mechanics use a large track-adjusting wrench and a pipe for additional leverage. A cover plate with three cap screws must be removed before the adjusting nut can be reached. Three additional tools and a lot of work are eliminated by the new design.

Quick access to the engine and radiator is being made possible by rerouting hydraulic lines to permit the cylinders, tank, hose and pump to be removed on a unit. At the present time, it is necessary to remove the complete hydraulic assembly with its various components to repair the radiator or get to the hydraulic unit. It is also necessary to remove the hydraulic components when taking out the engine. This requires draining of the hydraulic system and results in the loss of fluid.

Probably the most simple, yet time-saving, change being made is the installation of hinges on the two-piece radiator guard. It formerly required three men to remove or place this guard in position. One man can now swing it open.

The 'dozer's seat and fuel tank must be removed, usually with a small crane and two men, to make adjustments or take out the steering clutch. A new dowel arrangement will be employed to locate tie-down holes, and a small pedestal to hold the seat in a raised position to allow easy accessibility to the clutch.

Similar changes are also being made on the motor grader, another piece of engineer equipment familiar to heavy equipment mechanics.

The program is continuing in an effort to modify additional pieces of earthmoving equipment for the benefit of the maintenance man. It is hoped that this program will lead to eventual cooperation with industry to obtain ease of maintenance characteristics in the initial design of equipment for the Armed Forces.

The program may also be helpful to commercial earthmoving manufacturers, who may be able to adopt some of the techniques developed by Army engineers.

New Coating Process for Sprayer Tanks.—A new coating process which is expected to more than double the life of power sprayer tanks by preventing premature "rusting out" has been developed by The F. E. Myers & Bro. Co., Ashland, Ohio, manufacturers of power and hand sprayers for insect, pest and weed control and liquid fertilization.

The new process, which bonds a tough, impenetrable coating to sheet metal, will be used on the tanks of all larger models of Myers Power Sprayers. Other sheet metal parts, such as radiator hoods and engine covers, also will be treated. The first sprayers using the new process will appear on the market this spring.

The new coating process is the result of a study by Myers of bonding methods used in other industries as well as tests on various types of coating to find a combination which would successfully retard corrosive action on sprayer tanks by adverse weather conditions and spray chemicals.

Hundreds of tests have been run by Myers engineers on sheet metal treated with the new process. In one test,

treated metal panels were scratched and immersed in a salt brine solution for over a year. The only rust on the panels after a year's time was in the thin scratch where the bare metal was exposed. The coating successfully prevented the rust from creeping under the paint and loosening it.

Other panels were tested by immersing them in various spray chemicals which have been known to cause severe corrosive or solvent action on spray tanks. A number of different liquid fertilizers also were tested. The panels showed no indication of paint softening or loosening from the action of these chemicals. The popular solvents for spray chemicals, which have caused severe damage to ordinarily painted sprayer tanks, had no effect on the new coating for Myers sprayer tanks.

Another advantage of the new process, revealed in tests, showed that severe blows which will dent or crumple a sprayer tank will not break the coating and expose the bare metal to further damage.

Portable Telephone System.—A new, portable, G. I. telephone system, which can handle three times as many conversations over a single cable as comparable Korea and World War II systems, has been developed for the U. S. Army Signal Corps by Bell Telephone Laboratories.

Basic equipment for the new telephone system is contained in units about the size of large suitcases which can be handled by only one or two men. These units are designed so they can be stacked one on another. The "carrier" principle used for the new system allows twelve conversations to share the same cable by using a different frequency for each.

The system, providing for twelve simultaneous conversations, can be used for distances up to two-hundred miles. Another, a four-channel system, can be used for four simultaneous conversations at distances up to a hundred miles. Several of these wire systems linked together can form a communication system of about a thousand miles. They may also be operated in conjunction with a G. I. radio relay system developed at Bell Laboratories.

Recently developed miniaturized parts can be credited with the sharp reduction in size and weight of the new equipment. The earlier, four-channel unit, for example, weighed 475 lbs. and occupied 20 cu. ft. of space. Complete with its power supply, the new four-channel terminal weighs 178 lbs. and occupies only 5½ cu. ft. of space. The cable used for the systems can be strung on poles, laid on the ground, or buried.

New type repeaters have also been designed, to be used at intervals in order to restore the level of the transmitted signals and extend the range of the systems.

Important new features facilitate testing and maintenance while all regular channels are in service. A portable test set provided with the twelve-channel system contains a transistor oscillator, one of the first applications of the Bell Laboratories-invented transistor in quantity-produced military equipment.

Field equipment designed by the Laboratories for the Army is tested for its ability to withstand desert heat and arctic cold. It is subjected to vibration, bounce and shock tests, exposed to 100 per cent humidity and to wind and rain.

The new military carrier systems have recently been placed in production by the Western Electric Co., manufacturing unit of the Bell System.

Giant Liquid Rheostat for Hypersonic Wind Tunnel.—The largest rheostat of its kind in the world, able to dissipate 3300-kw, has been built by the General Electric Company's Industry Control Department for the Air Force's Arnold Engineering Development Center, Tullahoma, Tenn. Ordered by Foster Wheeler Corporation, New York manufacturing and construction firm, the rheostat will be incorporated into a wind tunnel installation by Consolidated Western Steel Division of U. S. Steel.

The rheostat will be used to vary current passing into giant heaters that regulate temperature of air passing through the test section of the wind tunnel. The heated air, driven by compressors, makes possible tremendous velocity. As a result, hypersonic wind conditions are available for testing aircraft models that travel at unusually high speeds.

Weighing 40,000 lbs. when full, the rheostat has three pumps that each force 225 gal. of electrolyte per minute. Contrary to normal practice where the wye point is grounded, the rheostat is built so that each phase is insulated from the other two phases. Large mounting bushings insulate each phase from ground.

Inner Workings (*Industrial Bulletin of Arthur D. Little, Inc., No. 317*). —Two applications of high-energy radiation are now approaching commercial importance. One of these is "cold sterilization"—the treatment of materials with radiation, rather than heat, to sterilize, pasteurize, or prevent spoilage. The other is the modification of the structure and physical characteristics of materials through irradiation. Both purposes have been accomplished with electrons from high-voltage accelerators; research on the use of fission by-products from nuclear reactors, for the same purposes, is under way.

The goal of cold-sterilization research is threefold—to develop a system for preserving foods that is cheaper and simpler than the heat treatments now used, to extend the shelf life of various foods, and to extend the number of foods that can be preserved. Meat, for example, must be cooked far longer than the optimal time for retaining proper flavor in order to achieve sterilization of the interior for long-term preservation. Vegetables and many liquids present the same problem; canned food products that are satisfactorily sterile lack the fresh taste. To get cold sterilization "over the hump" and to test irradiated products for flavor as well as nutritional value, the Army Quartermaster Corps has already initiated a $5- to $6-million research program, as a part of which ten men will live on a diet of irradiated foods for a year. Medical, nutritional, and processing studies are under way to solve the technical problems remaining before cold sterilization can be fully utilized in the food industry.

Two kinds of radiation may be used in sterilizing food—electrons from a specially designed high-voltage generator, and the gamma radiation, similar to "hard" X-rays, given off by atomic fission by-products. The electron technique is at present farther advanced, but there are capital cost problems. A 12-kilowatt high-voltage machine costs $400,000, and the price increases rapidly as the power rating goes up, but such a machine can generate an electron beam powerful enough to sterilize 2850 pounds of product per hour. On the unit basis, therefore, costs are approaching levels of commercial acceptability.

AJAX Engineering Corporation, Trenton, N. J., wishes to correct a temperature figure which was given in their advertisement in this JOURNAL for April, 1955. The statement was made that the temperature of the melt is held at 870° F. This should have been 1170° F.